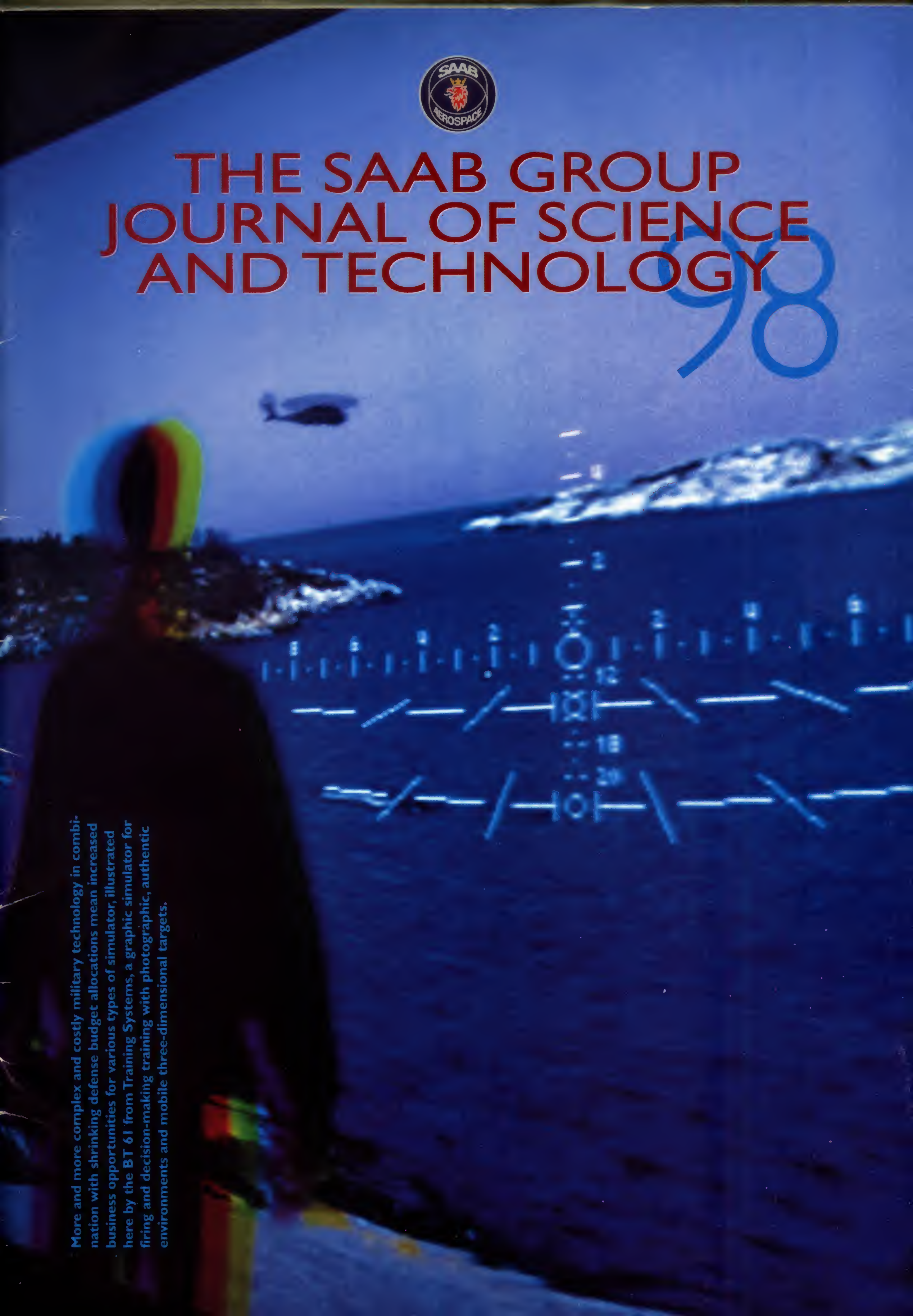
THE SAAB GROUP JOURNAL OF SCIENCE AND TECHNOLOGY 98



More and more complex and costly military technology in combination with shrinking defense budget allocations mean increased business opportunities for various types of simulator, illustrated here by the BT 61 from Training Systems, a graphic simulator for firing and decision-making training with photographic, authentic environments and mobile three-dimensional targets.

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Foreword

Developing and producing products at the cutting edge of technology is exciting and challenging. For employees at Saab, however, it is routine. Our company conducts operations in the aircraft, space, defense and other industries, and our products belong to the world elite in all these areas. The technological breadth and high level of expertise which the Saab Group represents is unique. Gripen is one example of this – the world's first fourth-generation fighter in service.

For more than 60 years, Saab's products have spearheaded technological development. This is due to the creativity of our staff and our ability to system-integrate. We have a strong tradition and big ambitions for a future where technologies will develop at a rapid pace. One key is integrating many different technologies for advanced products, another is applying existing technology in new areas.

Creativity, combined with advanced technological expertise has resulted in a series of innovations and spin-offs. Several of the existing business units such as Dynamics, Space and Marine Electronics have their roots in the aircraft operations. The Combitech business area's aim is to develop and market new spin-offs from defense-related business.

Advanced products require that our staff see the overall picture without having to understand each component in detail. Saab's products are the result of the integration of many technologies and areas of skill, which no one employee can possess. This places great demands on our engineers. They have to combine advanced knowledge of technology and the ability to communicate with other experts to find new solutions together. Just over 2,000 people at the Saab Group today work on research and development. In relative terms, Saab invests more in R&D than any other Swedish company.

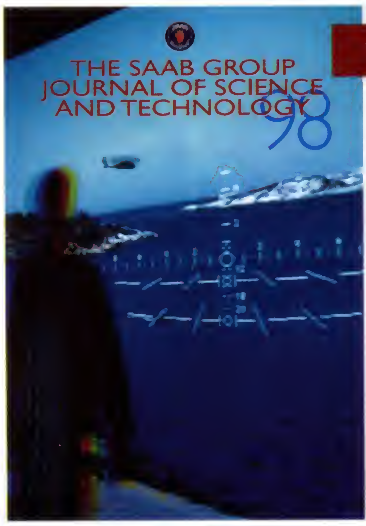
Working together with other companies, academic and research institutes both here and abroad is an important part of ensuring the continued supply of technology and expertise. These partnerships are growing in scope. Saab actively participates in many research programs, a substantial number of which are connected with the European Union. We also work closely with technical colleges. One example of this is our support of the Saab professorship in reliable and robust real-time systems at Chalmers University of Technology in Sweden, as described in this issue.

Our engineers have a key role. A company at the forefront of technology is naturally in need of the most qualified staff for all its areas. Through a close working partnership among the companies in the Saab Group, there are major opportunities for enhancing and broadening the skills of each individual employee. We can offer a creative and stimulating environment in which to work and develop.

Through this journal, we want to give you a foretaste of the exciting activities in the many technical areas covered by the Saab Group. We hope that you enjoy it.

Bengt Halse
Chief Executive Officer

Billy Fredriksson
Vice President, Corporate Technology



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by Christer Hoberg
Combitech Software AB

Competitiveness – ideas on professional knowledge

Christer Hoberg has an MSc in electrical engineering and is Managing Director of Combitech Software. He has worked with software development for over 20 years, initially at Ericsson, then as consultant and regional manager at ENEA DATA. He was involved in establishing Combitech Software in 1992.

"The most interesting aspect of tacit knowledge is the way we develop our judgement. At the core of tacit knowledge is the ability to make assessments and deal with unforeseen situations. In other words, to be able – within a given area – to work in harmony with life's various surprises."

Extract from "Professional expertise and technology – a research area", by Professor Bo Göranzon, Dean of KTH School of Industrial Management.

Combitech Software is a consultancy company with more than 100 engineers today working in software for real-time systems. Our customers are development departments at major product-developing companies in Sweden. To be competitive for customers and the labor market, it is necessary that we concentrate on the development of expertise.

The development of professional knowledge is traditionally steered by progress meetings and development plans connected with the company's goals. During our own company's first five years, we found that there were seldom any problems in finding paths of development during an employee's first couple of years. A combination of courses and seminars gives a basic knowledge which can be implemented in projects. However, it is much more difficult to make those paths more concrete for those who have more experience. This applies especially to those who do not want to specialize in technical areas but want to keep their expertise on a broader plane through systems development. This is not due to there being no more to learn; quite the reverse, we make sure that those with 10-15 years' experience from different projects can deal with complex work tasks that those with less experience cannot handle without support. Such tasks include producing the first architecture and design-related ideas for a system. The central questions for us are: of what does this knowledge consist? How can it be developed? How does one pass it on? And, most importantly, how do we find a way to develop the professional knowledge of systems developers?

From novice to expert

We have started a project which is now being carried out in collaboration with KTH School of Industrial Management and Professor Bo Göranzon, who has spearheaded research in professional knowledge for 15 years. The project is based on questions from a knowledge-theory perspective and includes the following starting points:

- Knowledge can be divided into 'formalized' knowledge and 'tacit' (or experience-based) knowledge. Tacit knowledge is different from formal knowledge in that it cannot be reproduced exactly; you cannot, for example, learn it from an instruction manual.
- Experience-based knowledge manifests itself in sound judgement and the ability to deal with situations, something which is passed on to others by example and developed through reflection and dialogue.

One model for developing professional knowledge – courtesy of Hubert Dreyfus – has the following five stages:

Novice. A novice is introduced into an area by being presented with a number of facts and characteristics, as well as precise rules with which to process these facts. The novice learns how to master a limited number of rules.
Advanced novice. The advanced novice receives practical experience in real-life situations and learns to detect the presence of elements that cannot be defined exactly. The rules for dealing with problems are connected to their "situational elements".
Competent. The competent person learns to deal with an overwhelming number of elements by choosing and implementing a plan.
Skilled. The skilled person experiences new situations from certain angles, in line with previous events and experiences. Certain characteristics in each situation are clear while others disappear into the background. He/she can, for example, unconsciously detect the arrival of a problem.
Expert. The expert experiences problem solving as routine.

The goal of the project is to produce methods that enable employees to develop more quickly from the novice stage to the expert stage.

One of these methods is so-called dialogue seminars, which have been developed in the 'professional knowledge and technology' area of research at KTH. This area of research has been built around case studies produced by doctors, process operators, meteorologists and forest technicians. It has a knowledge-theory perspective and its starting points have been developed by Professor Kjell S. Johannessen. It is also based on the philosophy of language as preached by aircraft engineer and philosopher, Ludwig Wittgenstein. The book "Writing as a Method for Reflection", by Maria Hammarén, has provided the structure of the preparatory work for the seminars. An important part of this preparatory work has been to read articles and literature relevant to the theme of the seminars. These have provided perspectives and starting points to the participants' own writing. This results in texts that describe the participants' own experience of the various stages of their work as well as parts of the systems development profession, such as fault tracing, problem solving, utilization of methods, etc. Using dialogue as a method, the seminars have created concepts such as clues, "going by the book", insight/distance, intuitive/discursive thinking, creativity and rhythm, which have become important in describing how professional knowledge will manifest itself in different situations. In the group, these terms are given a meaning through the examples described in the texts and, within the group, we have started to evolve a practice for systems development – a common view of what is considered to be the best way of dealing with a problem given the existing conditions.

A common view

These seminars have also influenced our view on how we must improve the systems development process in our overall undertakings. It is not enough to improve rules such as method and process descriptions, thereby creating more effective teamwork in the organization through better definitions. We must also develop a common view of what is sound judgement. This requires a lot of work but gives an incomparable competitiveness. The dialogues, based on examples and analogies, become the most important components for developing teamwork.

Those concepts that we have decided are central now form the basis of our continued efforts to develop the forms by which, when the time comes, we can effectively pass on and develop professional knowledge. These forms will be, for example, to introduce a type of mentorship which is similar to the master-apprentice relationship. This is mainly to develop those who are relatively inexperienced. For those who have more experience, it is important to exchange experiences and learn from others' mistakes. The method for such an exchange of information will be seminars of the type used in the project, i.e. dialogue seminars.

A similar project has been carried out at Statoil and we will be participating in a joint seminar with this group and the management of Statoil. A collaboration has also been initiated with MIT, Stanford and the technical college in Trondheim. The results of the project will be compiled in the book "Precision and Improvisation", which will be presented at the international conference, "Dialogue and Performing Knowledge", which is being held in Stockholm in October 1998.

The project will also be included as part of a network between KTH and other European colleges with their own case studies.

The continuing process

The process of establishing the passing on of experience as an integral part of business operations will continue in several areas. During the coming year, dialogue seminars on themes such as software architecture, testing and development models will be used to develop a common practice within the company.

In Saab Software Center, a newly established joint initiative by Combitech Software and the Gripen business unit in Linköping, project teams will be created to develop advanced software such as control and guidance systems, time-critical operations support systems and safety-critical real-time systems. Here we will implement dialogue seminars and master-apprentice systems to create an effective development of knowledge with experienced systems developers working together with graduates.

by Martin G. Helander
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Simulation and Modeling of Pilot Performance

Dr. Martin Helander is Professor of Human Factors Engineering in the Mechanical Engineering Department at Linköping University. He is also the Director of the Swedish Center for Human Factors in Aviation. Since receiving a Ph.D. from Chalmers University of Technology, he has been working as a faculty member at Luleå University and Virginia Tech. University at Buffalo, and has held a visiting appointment at MIT. He has published extensively in the areas of automation and human-computer interaction. Dr. Helander is an elected Fellow of the Human Factors and Ergonomics Society of the USA and the Ergonomics Society of the UK. He is the current President of the International Ergonomics Association.

A Systems Approach to Ergonomics

Human Factors (or Ergonomics) is the scientific discipline that is concerned with the interaction between humans and artifacts. The purpose is to design systems, jobs, products and environments that match the physical and mental abilities and limitations of the operator or user (Helander, 1997). A complementary approach is to extend the abilities and competence of operators through training. Ideally, however, systems should be designed so that they are largely intuitive to use and do not require much training or education.

Most human factors problems are well described by a systems approach. In Figure 1, we consider an environment-operator-machine system. The operator is the central focus in HF and should be described in an organizational context, which is the purpose of Figure 1.

In scientific studies a classification of independent and dependent variables is used to structure problems. Since ergonomics studies the effect of environmental and machine design features on the operator, the dependent variables are associated with the operator subsystem. These are detailed in Figure 1, and include measures of negative and positive outcome and satisfaction. The independent variables are associated with design parameters of the environment and the machine (such as alternative task allocation schemes, different controls and displays).

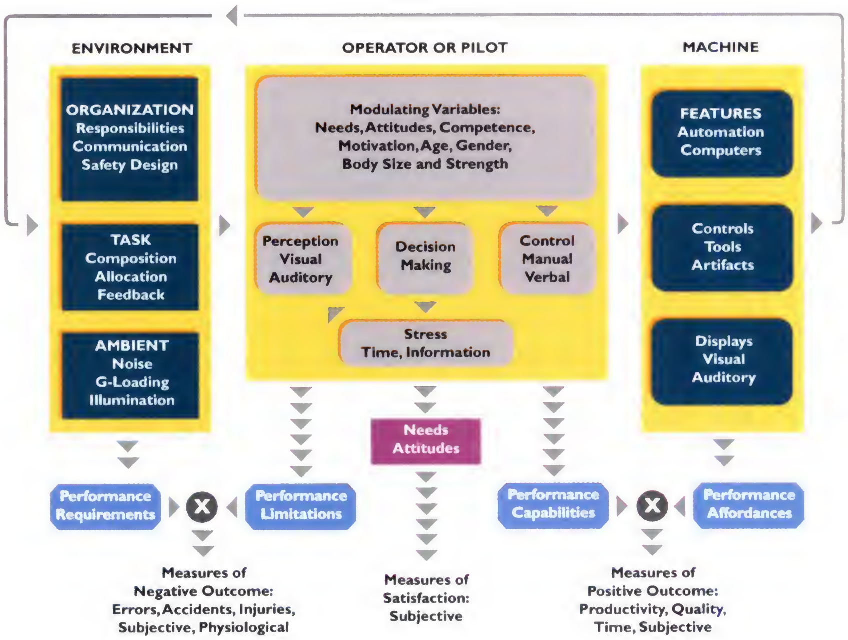

Figure 1: Human factors systems model for measurement of safety and productivity

The operator perceives the environment – mainly through the visual and auditory senses – then considers the information, makes a decision and finally produces a control response. Some decisions become automatic with training/experience, while other decisions require slow deliberation of various alternatives for action. For new or unusual tasks, decision making can be time-consuming. The operator will have to interpret the

information and to what extent action alternatives are relevant to the goals of the task. For routine tasks, decisions are more or less automatic and quick to accomplish. Klein (1993) uses the concept of "situated action" as an alternative to decision making. In aviation we would hope that tasks are so well designed and understood that decision making is automatic. Deliberate pondering of alternatives and deep thinking takes too much time.

There are several variables that modulate the operator's response, including operator needs, attitudes, competence, expertise, motivation, age, gender, body size and strength. These are idiosyncratic variables and they vary between individuals. For example, an experienced, competent pilot will perceive a task differently from a novice pilot. He or she will focus on details of importance (rather than unimportance), automatically filter irrelevant information and "chunk" the remaining information into large units so that it is possible to make fast and efficient decisions.

Stress is an important variable that affects perception, decision making and response selection. High psychological stress levels result when the time to perform a task is limited or when there is too much information to process. In general, high stress levels lead to increased physiological arousal and can be monitored by using various physiological measures (e.g. heart rate, EEG, blink rate and excretion of catecholamines). The Environment sub-system is used to conceptualize the task as well as the context in which it is performed. It could be an air traffic controller. Here organization of work determines the task allocation; some tasks may be allocated to fellow workers, supervisors or computers. Task allocation is a central problem in ergonomics: how can one best allocate work tasks among machines and operators so as to realize both company goals and individual goals? Task allocation affects how information is communicated between employees and computers, and it also affects systems performance.

The operator receives various forms of feedback from his/her actions. There may be feedback from task performance, from co-workers, from management and so forth. To enhance task performance, communication and job satisfaction, such feedback must be rich, frequent and informative. Individuals must receive feedback on both how well or how poorly they are doing.

The ambient environment describes the influence of environmental variables on the operator, such as noise, G-forces, vibration, etc. This increases physiological arousal and stress, thereby affecting task performance, safety and satisfaction.

The importance of the organizational environment has been increasingly emphasized during the past few years. Human factors measures are undertaken in an organizational context, which deeply affects the appropriateness of alternative design measures. Company policies with respect to communication patterns, decentralization of responsibilities and task allocation have an impact on HF design; one should first decide who should do what and how people should/could communicate. Then individual tasks, machines, displays and controls can be designed.

The machine sub-system is broadly conceptualized in Figure 1. It symbolizes any artifact – a computer, a tool or an aircraft. The term "controls" denotes machine controls which are used by the operator. Note that machine control may be taken over by automation and computers through allocation and delegation of tasks to autonomous processes. As a result of machine control, there is a changing state which is "displayed", typically on a computer. The system in Figure 1 is dynamic – machine information is fed back to the environment sub-system and becomes integrated with the task. Human factors is exclusively concerned with dynamic systems – it is necessary to go around the loop and incorporate the effect of feedback and study its effect.

THE GOAL OF SAFETY

Human factors/ergonomics is rarely a goal by itself. Safety, operator satisfaction and productivity are common goals. HF is rather a design methodology that is used to arrive at safety, productivity and satisfaction.

The safety status of a system can be assessed by comparing the performance requirements of the environment with the performance limitations of the operator (Figure 1). If the task demands are greater than the available performance there is an increased risk of accidents or errors. Hence it is important to understand how the limitations imposed by operator perception, decision making and control action can be taken into consideration in design, so as to create systems with low and stable performance requirements.

THE GOAL OF PRODUCTIVITY

To enhance system performance one can design a system which improves performance affordances. This means that through efficient design of the system the operator can excel in exercising his/her skills. Such system design makes it possible for the operator to perceive quickly, make fast decisions and exercise efficient control.

Design should enhance important skill parameters so control handling becomes intuitive (e.g. through control-response compatibility) and interpretation of displays becomes instantaneous (e.g. through use of ecological displays).

Figure 1 lists several dependent variables: productivity, quality and time to perform a task. All of these can be objectively measured. One can also ask the operator how well the system works; this is a subjective measure. These dependent variables are traditionally used in research to measure the productivity of a system.

THE GOAL OF OPERATOR SATISFACTION

Satisfaction or dissatisfaction may be predicted by comparing operator stated needs and attitudes with how well the performance requirements and the performance affordances fulfil an

individual's needs. One can of course also ask the person directly how satisfied they are.

Since needs and attitudes differ much among different individuals, some users can be satisfied with a system while others are dissatisfied. Needs and attitudes vary substantially between countries and cultures, and they also depend on competence and education. This should be observed in testing of aircraft by test pilots. It is important to measure not only central trends but also standard deviation. Test pilots sometimes have very diverging opinions which are often suppressed in the test protocol.

The Trouble with Information

The main problem in the cockpit or in ATC is that there is too much information – and the trend is increasing. As a result the pilot needs more time for decision making and action, which may not be compatible with the flight situation.

There are two laws in Human Factors that relate to information overload: Hick's law and Fitts's law. Both laws state that an increase in entropy (or uncertainty) increases performance time (Wickens, 1992).

Hick's Law states:

Reaction Time = C Log n

where n = number of decision alternatives, which usually are expressed in bits of information, see Figure 2. Eight alternatives = 3 bits. Four alternatives = 2 bits, etc. Note in Figure 2 the straight linear relationship between amount of information and reaction time.

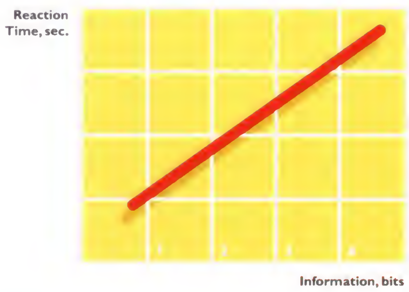

Figure 2. Hick's Law

Fitts's law can be used to predict the manual movement time between two targets. The experimental task is typically to move a pen back and forth between the two target areas as quickly as possible. Fitts's law predicts that the movement time depends on the relative precision D/W of the movement:

Time = C Log D/W

where D is the distance between the two target areas and W is the target width. This equation is also an expression of entropy.

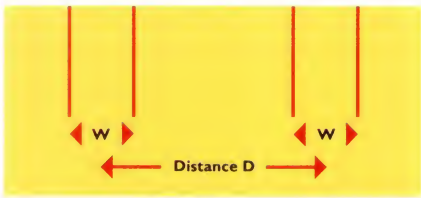

Figure 3. Fitts's Law

THE TROUBLE IN MAKING DECISIONS

After a pilot has accessed information, there is the difficulty of making decisions. There are many biases in human decision making, such as (Wickens, 1992):

Salience Bias (Payne, 1980).
Paying most attention to salient information.

"As If" Heuristic (Johnson, 1973).
As if all information was equally valuable.

Ignoring Arithmetic Calculations

Availability Heuristic
(Tversky, 1974).
Available hypotheses favored.

Reversed Causal Reasoning
(Eddy, 1982).
A implies B means that B implies A.

Confirmation Bias (Einhorn, 1978).
Looks for confirming information.

Overconfidence in Diagnosis (Kleinmuntz, 1990).
E.g. the weather forecast.

These biases, many of which are imposed by the limitations of short-term memory, make it difficult for pilots to make reliable decisions in unfamiliar or unexpected situations. Pilots have, for example, great difficulties in calculating probabilities of outcome. To help with these difficulties and the biases listed above, computerized decision support systems would be valuable – particularly for military applications. To be compatible with the pilot, such systems have to be based on a human model. The design of decision support is therefore of great interest to human factors.

Simulators for Training

Simulators are commonly used for training in air traffic control as well as flying. It is important to consider some of the basic principles of training that have been proved to enhance learning. These principles should if possible be incorporated into the training procedures used in simulators. Below we list five well established principles of training.

1. Practice and Overlearning
Practice makes perfect – but how perfectly is it necessary to be able to perform a task? Most skills continue to improve with practice over time. Pilots (especially military pilots) rely on automaticity of performance for a great range of tasks, and need extensive training.

2. Reducing concurrent task load
Effective training will not take place in a high workload environment.

3. Error Prevention
Do not allow errors to be repeated, because they will be learned. This can be accomplished, for example, through "guided training", such as when the ideal flight path is painted on a display. This is good for learning a new task. However, pilots may become so dependent on this feature that they do not perform well without it.

4. Provide Knowledge of Results (KR)
Performance feedback should be given right after the task, so that the learner remembers what he or she did.

5. Transfer of Training
Try to capitalize on what a pilot learned before, so that situations of positive transfer are created. Positive transfer depends, however, on the

similarity of the new situation compared to the old situation.

Assuming that a pilot has been flying aircraft A and is learning to fly aircraft B, if the displays and controls are different one may get negative rather than positive transfer of training. This means that the previously learned skills hinder task performance in the new environment (see Table 2).

Displays	Controls	Transfer
Same	Same	Strong Positive
Same	Different	Negative
Different	Same	Positive
Different	Different	Zero

Table 2. Transfer of training is enhanced if the controls of two aircraft are similar.

VALIDITY OF SIMULATORS FOR TRAINING

Then validity of a flight simulator for training depends on the type of task being trained as well as the type of simulator used. Based on comparisons of the effectiveness of a simulator one can calculate Transfer Effectiveness Ratio: TER = (amount of savings)/(simulator time).

> Example: Assume that it takes 10 hours to learn a procedure while flying a real aircraft. To save costs there are three different simulators available, A, B and C.
>
> A pilot used simulator A for 4 hours, which saved him 2 hours' flying time.
> TER = 2/4 = 0.50
> Positive transfer of training.
>
> A pilot used simulator B for 4 hours, which prolonged the flight training by 3 hours.
> TER = -3/4 = -0.75
> Negative transfer of training.
>
> A pilot used simulator C for 1 hour, which saved 1 hour of flight time.
> TER = 1/1 = 1.0
> Perfect positive transfer.

Simulators in Human Factors Research

Simulators are commonly used in HF studies to evaluate a variety of issues, including: avionics and handling, malfunctions and error recovery, display and control design, and crew resource management. Below we present as examples two studies where simulators were used.

STUDY 1

Chou, Madavan and Funk (1996) studied errors in Cockpit Task Management (CTM), how to initiate, monitor, prioritize and terminate cockpit tasks. CTM errors were found in 23% of 324 accidents. In a low-fidelity simulator they set up tasks with high or low workload. They also evaluated flight paths with high or low complexity. In the simulator they measured the dependant variables mentioned in Table 3. The results are also given in Table 3. For example, for high workload the response time to system faults was greater than for low workload, but there was no difference for RMS flight path errors.

	High workload	Difficult flight path
Response time to system faults (sec)	Stat. sign.	Stat. sign.
Root-mean-square flight path error	Not sign.	Not sign.
Task prioritization	Stat. sign.	Stat. sign.
Late task initiation	Stat. sign.	Stat. sign

Table 3. Dependent and independent variables and results of statistical testing.

The following recommendations were made:

1. Train pilots how to avoid CTM errors
2. Check on the validity of the present simulation by using full-mission simulation
3. Develop memory aids, such as the well known: "Aviate, Navigate, Communicate"
4. Develop decision support aid to:
   - Monitor task state and status,
   - Compute task priority,
   - Remind pilots of all tasks in progress,
   - Suggest to pilot to attend critical tasks.

STUDY 2

Caldwell, Caldwell and Crowley (1997) studied whether Dexedrine can be used to sustain the performance of sleep-deprived female helicopter pilots.

US Air Force pilots during the Iraq war had previously claimed that Dexedrine (an amphetamine) was useful. Six female pilots flew a high-fidelity flight simulator with either Dexedrine or a placebo. The tests took five full days and for two of the days there had not been any prior sleep. The following dependent variables were used: EEG, mood state and flight performance test for several different maneuvers.

The results were that Dexedrine improved performance for a majority of the maneuvers studied. It increased EEG (delta and theta bandwidth) activity and improved pilot mood state. Dexedrine can be a viable countermeasure against fatigue in female pilots.

The Development of Virtual Environments

The use of virtual environments with full immersion may offer new possibilities for simulation. There are, however, still many problems with full-immersion virtual reality (VR): adequate head tracking, low resolution comparable to CRT technology, motion sickness, eyestrain, neck strain, etc. But technology improves rapidly.

No matter how sophisticated or inexpensive the VR technology, the key question is to identify those tasks that are so enabled by VR that users will choose VR over other alternatives.

The apparent applicability of VR to practically anything is not credible. Technology derives its power from its specificity and its customizability (Bazalla, 1988). The first LINK trainer which taught an aircraft's response to control inputs was a commercial failure. A later model designed for the purpose of relating control inputs to flight instrument readings was a success. An aircraft simulator is valuable

not because it can simulate an aircraft but a Boeing 747SP. The requirement for specificity is quite an order, and may not be easily achieved (Ellis, 1997).

Are there "killer applications" of VR? What we are looking for are probably tasks that involve frequent manipulations of objects in complex visual environments and also require frequent changes in viewing position, for example telerobotic-like tasks, including UAVs and distributed command and control, endoscopic surgery, maintenance training for complex machinery (which may be disassembled in VR) and architectural design.

But for other applications the egocentered frame of reference provided by the head-mounted display may not provide an advantage compared to regular displays.

Conclusion

The limited capacity of the human information processing system and decision making makes it necessary to design information displays with the human in mind. Careful experimentation is necessary. For many experiments simulation studies are adequate. Simulators may also be used for training purposes. Whatever the application – training or experimentation – it is important to understand whether the fidelity of simulation is adequate for the purpose. Human factors offer methodologies for all three purposes. They can help in the use of simulators in research, training and the measurement of required fidelity and validation.

References

Basalla, G. (1988). *The Evolution of Technology* (New York: Cambridge University Press).

Caldwell, J.A., Caldwell, J.L., and Crowley, J.S. (1997). "Sustaining Female Helicopter Pilot Performance with Dexedrine during Sleep Deprivation" (*International Journal of Aviation Psychology, 7*, pp. 15-36).

Chou, C.-D., Madavan, D., and Funk, K. (1996). "Studies of Cockpit Task Management Errors" (*International Journal of Aviation Psychology, 6*, pp. 307-320).

Eddy, D.M. (1982). "Probabilistic reasoning in clinical medicine: Problems and opportunities" in Khaneman, D., Slovic, P., and Tversky, A. (Eds.), *Judgement under uncertainty: heuristics and biases* (New York: Cambridge University Press).

Einhorn, H.J., and Hoghart, R.M., (1978). "Confidence in Judgement: Persistence in the illusion of validity" (*Psychological Review, 85*, pp. 395-416).

Ellis, S.R., Begault, D.R., and Wenzel, E.M. (1997). "Virtual Environments as Human Computer Interfaces" in Helander, M.G., Landauer, T.K., and Prabhu, P.V. (Eds.), *Handbook of Human-Computer Interaction, 2nd Edition* (Amsterdam: North-Holland).

Helander, M.G. (1997, in press). "Forty Years of IEA: Some Reflections on the Evolution of Ergonomics" (*Ergonomics*).

Johnson, E.M., Cavanagh, R.C., Spooner, R.L., and Samet, M.G. (1973). "Utilization of reliability measures in Bayesian inference: Models and human performance" (*IEEE Transactions on Reliability, 22*, pp. 176-183).

Kleinmuntz, B. (1990). "Why we still use our head instead of formulas: Towards an integrated approach" (*Psychological Bulletin, 107*, pp. 296-310).

Payne, J.W. (1980). "Information processing theory: Some concepts and methods applied to decision research" in T.S. Wallsten (Ed.), *Cognitive processes in choice and decision behavior* (Hillsdale, N.J.: Erlbaum).

Tversky, A., and Kahneman, D. (1974). "Judgement under uncertainty: heuristics and biases" (*Science, 185*, pp. 1124-1131.

Wickens, C.D. (1992). *Engineering Psychology and Human Performance* (New York: Harper Collins).

Situation Awareness: The Future of Aviation Systems

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The Challenge of the Information Age

We are living in what has been termed the "information age". In the cockpit, this has meant a huge increase in avionics systems, displays and technologies. From voice control to sophisticated line-of-sight helmet-mounted displays, almost anything is possible in today's cockpit, but too much is proving to be as big a challenge as too little once was. The problem is no longer lack of information, but finding what is needed when it is needed.

This problem is not isolated to the cockpit. All around us, signs of this change are present. Whether you are working on the shop floor, in the world of business, or just trying to purchase a new computer for your home, the dizzying pace of technological change and vast amount of information present can be daunting. We are constantly being barraged with information through TV, radio, mailings and hundreds of magazines and journals. Within our companies, reports and forms have multiplied and every aspect of the business is recorded somewhere. Bringing all of this information together in a form which is manageable is quite a challenge. There is simply more information than anyone can handle.

Widespread communications networks allow us to communicate with colleagues in other cities and other continents as easily as we once communicated with our neighbors, whether they be at home, in the office, flying over the Atlantic ocean or hiking through the Andes. Matching that access for voice communication are fax machines, email and the World Wide Web, which bring text and pictures just as easily. And the computerization of information is only the most recent off-shoot of this information explosion. A rapid proliferation in the publishing world has seen a deluge of magazines, journals and books crowding our mailboxes and the shelves of our libraries. The world's great libraries are doubling in size every 14 years; 1,000 new books are published internationally every day and the number of scientific journals has increased to the extent that surveys show that the vast majority of articles go virtually unread. More new information has been produced in the past 30 years than in the previous 5,000 (Wurman, 1989).

Yet, in the face of this torrent of "information", many of us feel even less informed than ever before. This is because there is a huge gap between the tons of data being produced and disseminated, and our ability to find the bits that are needed and to process them together with the other bits to arrive at the actual information that is needed. This problem is real and ongoing, whether your job is in the cockpit or behind a desk. It is becoming widely recognized that more data does not equal more information.

<u>From Data to Information</u> Coming to grips with the challenge of the explosion of data is paramount and can mean the difference between success and failure in many endeavors. The recent Gulf War has been labeled "the first information war" (Campen, 1992; Mann, 1994). While many factors contributed to the great success of the coalition forces against Iraq, their ability to speed up the cycle of collecting, disseminating and using information to produce a new air tasking order every 72 hours (as compared to typical cycles of weeks) is considered a key component in that outcome. Coupled with this thrust was a highly successful program to severely disrupt the Iraqis' flow of information by destroying the command and control systems

that provided critical tracking information for their fighters and surface-to-air missiles, and by attacking Iraqi power grids and telecommunications centers, which effectively disrupted internal communications systems (Mann, 1994). This situation left the Iraqis severely hampered in their ability to marshal and direct their forces, detect and respond to coalition tactics, and function as a cohesive fighting force. The effect of this information dominance was a swift victory with an unprecedented minimization of casualties on the part of the coalition (Morton, 1995). While the information dominance was not complete (the coalition continued to have difficulty locating and destroying Iraq's mobile Scud missiles and strategic weapons facilities, for instance), the Gulf War effectively demonstrated the clear advantage of possessing information dominance in overcoming what was considered at the time to be a very large, highly trained and zealous fighting force that had the advantage of operating in its own back yard.

"This post-technological age has been defined as one in which only those who have the right information, the strategic knowledge and the handy facts can make it" (Bennis, 1977). This brings home a central truth of the age we live in. Success (and even survival) depends on rapidly sorting through, understanding and assimilating vast quantities of data. Whether one is in a commercial cockpit flying through thunderstorms and dealing with other air traffic, involved in a complex battlefield scenario with distributed forces, or operating a business in a competitive and dynamic world market place, making the right decisions will depend on having a good grasp of the true picture of the situation.

Success in these endeavors involves far more than having a lot of data. It requires that the data be transformed into the required information in a timely manner. In most contexts, the body of available data will need to be processed and interpreted slightly differently by different individuals, each of whom has varied and dynamically changing but inter-related information needs, and properly understood by each within the context of a joint mission (for example the pilot, co-pilot and air traffic control). Creating information from data is complicated by the fact that, like beauty, what is truly "information" is largely in the eye of the beholder. To support the information needs of all the parties in the system and to insure that they are all properly coordinated and "reading from the same page" is the critical task facing us. Achieving this goal depends on understanding how people process and utilize information in their decision making activities.

Understanding "Human Error"

In 1989, a US Air Boeing 737 failed to take off at New York's LaGuardia Airport, landing in the nearby river (National Transportation Safety Board, 1990). The precipitating cause was an accidental disarming of the autothrottle. Neither the captain nor the first officer was aware of the critical flight parameters needed to detect and correct the problem, thus the take-off was not aborted in a timely manner, resulting in the loss of the aircraft and two passengers.

More recently, a fully functional 757 crashed into a mountain top in Cali, Colombia, killing 159 people. In resolving an error resulting from entering an incorrect navigational fix, the pilots had lost awareness of where they were in relation to the mountainous terrain. Although GPWS provided a warning, they were unable to climb sufficiently to avoid the mountain top.

Outside Strasbourg, an Airbus crashed short of the runway. The most likely cause has been found to be a miss-entered glideslope (3,300 ft/min instead of 3.3°). The crew was apparently unaware that they were in the wrong mode in entering the data and were not aware that the glideslope they were on placed their path in the way of terrain.

The list continues. And it touches every aircraft type and every country of operation. No-one is immune. Mechanical failures are no longer the biggest concern in flying aircraft, nor the greatest factor leading to loss of hulls or fatalities. Neither is terrorism, although these issues probably gain more notice in the minds of the flying public. As we move into the 21st century, and the next 60 years of Saab's operation, the biggest challenge facing the aviation industry and the most likely cause of an accident receives the label of human error.

This is a most misleading term, however, that has done much to sweep the real problems under the rug. It implies that people are merely careless, poorly trained or somehow not very reliable in general. In fact, if you examine the vast majority of these accidents you'll find that the human operators were striving against significant challenges. On a day-to-day basis they cope with hugely demanding and complex systems. They face both data overload and technology overload. We drill into them long lists of procedures and checklists designed to cope with some of these difficulties, but from time to time they are apt to fail. Our response to this has been more procedures and more systems, but I'm afraid we only add to the complexity in the process. The human being is not the cause of these errors but the final dumping ground for the inherent problems and difficulties in the technologies we have created. The operator is usually the one who must bring it all together and overcome whatever failures and inefficiencies exist in the system.

Situation Awareness: The Key to Providing Information

So why are people having trouble coping with this technology and data explosion? The answer lies in understanding how people process the vast amount of data around them to arrive at effective performance.

If we examine these accidents, and many more like them, we see that the operators have no difficulty in physically performing their tasks, and no difficulty in knowing what is the

correct thing to do, but they continue to be stressed by the task of understanding what is going on in the situation. Developing and maintaining a high level of situation awareness is described by pilots as the most difficult part of their job. It is one of the most critical and challenging tasks in the air today.

Situation awareness (SA) can be thought of as an internalized mental model of the current state of the flight environment. All of the incoming data from the many aircraft systems, the outside environment, fellow crew members, other aircraft and ATC must all be brought together into an integrated whole. This integrated picture forms the central organizing feature from which all decision making and action takes place.

A vast portion of the aircrew's job is involved in developing SA and keeping it up to date in a rapidly changing environment. This is a task that is not simple in light of the complexity and sheer number of factors that must be taken into account in order to make effective decisions.

The key to coping in the "information age" is developing systems that support this process. This is where our current technologies have left human operators the most vulnerable to error. Problems with SA were found to be the leading causal factor in a review of military aviation mishaps (Hartel, Smith, & Prince, 1991) and, in a study of accidents among major air carriers, 88% of those involving human error could be attributed to problems with situation awareness (Endsley, 1995b). A similar review of errors in other domains (such as air traffic control or nuclear power) shows that this is not a problem that is limited to aviation but one we face with many of our complex systems. Success will go to the aircraft manufacturers and technology developers who understand how to combine and present the vast amounts of data now available from the many technological systems present in order to provide true situation awareness (whether it be to the pilot, the business manager or the automobile driver). The key here is in understanding that true situation awareness only exists in the mind of the human operator. Therefore presenting a ton of data will do no good unless it is successfully transmitted, absorbed and assimilated in a timely manner by the human to form situation awareness.

Due to its importance and the significant challenge it poses, finding new ways of improving SA has become one of the major design drivers for the development of new aircraft systems. Interest has also increased within the operational community which is interested in finding ways to improve SA through training programs. The successful improvement of SA through aircraft design or training programs requires the guidance of a clear understanding of SA requirements in the flight domain, the individual, system and environmental factors that affect SA, and a design process that specifically addresses SA in a systematic fashion.

<u>SITUATION AWARENESS DEFINED</u> Situation awareness is formally defined as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future"* (Endsley, 1988). Situation awareness thus involves perceiving critical factors in the environment (Level 1 SA), understanding what those factors mean, particularly when integrated together in relation to the aircrew's goals (Level 2) and, at the highest level, an understanding of what will happen with the system in the near future (Level 3). These higher levels of SA allow pilots to function in a timely and effective manner.

Level 1 SA – Perception of the elements in the environment

The first step in achieving SA is to perceive the status, attributes and dynamics of relevant elements in the environment. A pilot needs to perceive important elements such as other aircraft, terrain, system status and warning lights along with their relevant characteristics. In the cockpit, just keeping up with all of the system and flight data, other aircraft and navigational data can be quite taxing.

Level 2 SA – Comprehension of the current situation

Comprehension of the situation is based on a synthesis of disjointed Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present, to include an understanding of the significance of those elements in light of one's goals. The aircrew puts together Level 1 data to form a holistic picture of the environment, including a comprehension of the significance of objects and events. For example, upon seeing warning lights indicating a problem during take-off, the pilot must quickly determine the seriousness of the problem in terms of the immediate airworthiness of the aircraft and combine this with knowledge on the amount of runway remaining in order to know whether it is an abort situation or not. A novice pilot may be capable of achieving the same Level 1 SA as more experienced pilots, but may fall far short of being able to integrate various data elements along with pertinent goals in order to comprehend the situation as well.

Level 3 SA – Projection of future status

It is the ability to project the future actions of the elements in the environment, at least in the very near term, that forms the third and highest level of situation awareness. This is achieved through knowledge of the status and dynamics of the elements and a comprehension of the situation (both Level 1 and Level 2 SA). Amalberti and Deblon (1992) found that a significant portion of experienced pilots' time was spent in anticipating possible future occurrences. This gives them the knowledge (and time) necessary to decide on the most favorable course of action to meet their objectives.

<u>SITUATION AWARENESS REQUIREMENTS</u>

Clearly understanding SA in the aviation environment rests on a clear elu-

cidation of its elements (at each of the three levels of SA), identifying which things the aircrew needs to perceive, understand and project. These are specific to individual systems and contexts, and as such must be determined for a particular class of aircraft and types of mission (e.g. commercial flight deck, civil aviation, strategic or tactical military aircraft, etc.). In general, however, across many types of aircraft systems certain classes of elements are needed for situation awareness that can be described.

Geographical SA
Location of own aircraft, other aircraft, terrain features, airports, cities, waypoints and navigation fixes; position relative to designated features; runway and taxiway assignments; path to desired locations; climb/descent points.

Spatial/Temporal SA
Attitude, altitude, heading, velocity, vertical velocity, G loading, flight path; deviation from flight plan and clearances; aircraft capabilities; projected flight path; projected landing time.

System SA
System status, functioning and settings; settings of radio, altimeter and transponder equipment; ATC communications present; deviations from correct settings; flight modes and automation entries and settings; impact of malfunctions/system degrades and settings on system performance and flight safety; fuel; time and distance available on fuel.

Environmental SA
Weather formations (area and altitudes affected and movement; temperature, icing, ceilings, clouds, fog, sun, visibility, turbulence, winds, microbursts; IFR vs VFR conditions; areas and altitudes to avoid; flight safety; projected weather conditions.

In addition, for military aircraft, elements relative to the military mission will also be important.

Tactical SA
Identification, tactical status, type, capabilities, location and flight dynamics of other aircraft; own capabilities in relation to other aircraft; aircraft detections, launch capabilities and targeting; threat prioritization, imminence and assignments; current and projected threat intentions, tactics, firing and maneuvering; mission timing and status.

Determining specific SA requirements for a particular class of aircraft is dependent on the goals of the aircrew in that particular role. SA requirements can be determined for any type of system (commercial aircraft, military aircraft, etc.) by examining the goals of the operators in that particular mission and their decision requirements, and from that determining their situation awareness needs at each of the three levels.

Designing for Situation Awareness Enhancement

One of the key benefits of looking at situation awareness is that it tells us how all that data needs to be combined and understood. Instead of loading the pilot down with 100 pieces of miscellaneous data, provided in haphazard fashion, situation awareness requirements provide guidance as to what the real comprehension and projection needs are. Therefore it tells us, as system designers, how to bring those 100 pieces of data together to form meaningful integration and groupings of data that can be easily absorbed and assimilated in time-critical situations. This type of systems integration usually requires unique combinations of information and portrayals of information that go far beyond the black box "technology-oriented" approaches of the past. In the past, it was up to the pilot to do it all. This task left him or her overloaded and susceptible to missing critical factors. As we step up to the job of proving systems that support the SA process, however, we will do much towards aiding the most critical challenge in aviation today.

So how do we design our systems to meet this challenge? The answers are certainly not as straightforward as we all would like them to be, but neither are they as elusive as some might think. Over the past decade we have begun focusing research on this problem and have developed some understanding of the basic mechanisms that are important for situation awareness and the design features that will support those mechanisms. All of these factors are far too detailed to go into here, but three major steps can be discussed that will have much to do with how successful any company is in making its systems support situation awareness. A structured approach is required to incorporate SA considerations into the design process, including a determination of SA requirements, designing for SA enhancement, and measurement of SA in design evaluation.

SA REQUIREMENTS ANALYSIS Designing interfaces that provide SA depends on domain specifics that determine the critical features of the situation that are relevant to a given operator. A goal-directed task analysis methodology (Endsley, 1993) has been used successfully for determining SA requirements in several different domains, including aircraft, air traffic control and remote maintenance control centers. This methodology focuses on the basic goals of operators (which may change dynamically), the major decisions they need to make relevant to these goals and the SA requirements for each decision. SA requirements are established in terms of the basic data that areneeded (Level 1 SA), required integration of the data for a comprehension of system state in light of goals (Level 2 SA), and projection of future trends and events (Level 3 SA).

The method is significantly different from traditional task analyses in that: 1) it is not pinned to a fixed timeline, a feature which is not compatible with the work flow in dynamic systems; 2) it is technology independent, not tied to how tasks are done with a given system but to what information

is really, ideally needed; and 3) the focus is not just on what data is needed, but on how that data needs to be combined and integrated to support decision making and goal attainment. This last feature, defining comprehension and projection needs, is critical for creating designs that support SA instead of overloading the operator with data as many current systems do. The first step therefore must be carefully to determine just what SA factors a given individual needs to be aware of – not just what is available, but what he or she really wants to know. This analysis provides the most important foundation for successfully creating systems that support situation awareness.

SA-ORIENTED DESIGN Second, the development of a system design for successfully providing the multitude of SA requirements that exist in complex systems is a significant challenge. A set of design principles has been developed based on a theoretical model of the mechanisms and processes involved in acquiring and maintaining SA in dynamic complex systems (Endsley, 1995c). These guidelines are focused on a model of human cognition involving dynamic switching between goal-driven and data-driven processing and feature support for limited operator resources, including: 1) direct presentation of higher-level SA needs (comprehension and projection) instead of low-level data; 2) goal-oriented information display; 3) support for global SA, providing an overview of the situation across the operator's goals at all times (with detailed information for goals of current interest), enabling efficient and timely goal switching and projection; 4) use of salient features to trigger goal switching; 5) reduction of extraneous information not related to SA needs; and 6) support for parallel processing. To date, an SA-oriented design has been successfully applied as a design philosophy for systems involving remote maintenance operations and flexible manufacturing cells.

SA DESIGN EVALUATION Finally there are many concepts and technologies that are currently being developed and touted as enhancing SA. Prototyping and simulation of new technologies, new displays and new automation concepts is extremely important for evaluating the actual effects of proposed concepts within the context of the task domain and using domain-knowledgeable subjects. If SA is to be a design objective, then it is critical that it be specifically evaluated during the design process. Without this it will be impossible to tell if a proposed concept actually helps SA, does not affect it or inadvertently compromises it in some way. The Situation Awareness Global Assessment Technique (SAGAT) has been successfully used to provide this information by directly and objectively measuring operator SA in evaluating avionics concepts, display designs and interface technologies (Endsley, 1995a). This technique is currently being used to evaluate everything from graphic displays for aircraft to automation concepts, to advanced free flight and to the F-22. Careful evaluation using many of the advanced simulation and virtual reality devices discussed here today is perhaps the greatest tool we have for ensuring that the systems we develop really support the situation awareness needs of the human operator.

Conclusions

We spoke earlier about how the need to process and understand large volumes of data was critical to many endeavors, from the cockpit to military missions, from power plants to automobiles, and from space stations to day-to-day business operations. The lessons we are learning in advanced aircraft about the importance of good situation awareness, the challenges that we face in achieving it and the design principles that are needed to support it, all provide valuable directions for these areas as well. We will not realize the benefits of the information age until we come to grips with the challenges of managing this dynamic information base to provide people with the situation awareness they need on a real-time basis. Doing so is the primary challenge of the next decade, for Saab and for us all.

References

Amalberti, R., & Deblon, F. (1992). "Cognitive modeling of fighter aircraft process control: a step towards an intelligent on-board assistance system" (*International Journal of Man-machine Systems, 36, pp. 639-671*).

Bennis, W. (1977). "Thoughts from a victim of info-overload anxiety" (Yellow Springs, OH: *Antioch Review*).

Campen, A. (1992). *The first information war: The story of communications, computers and intelligence systems in the Persian Gulf war* (Fairfax, VA: AFCEA International Press).

Endsley, M. R. (1988). "Design and evaluation for situation awareness enhancement" in *Proceedings of the Human Factors Society 32nd Annual Meeting* (Santa Monica, CA: Human Factors Society), pp. 97-101.

Endsley, M. R. (1993). "A survey of situation awareness requirements in air-to-air combat fighters" (*International Journal of Aviation Psychology*, 3(2), pp. 157-168).

Endsley, M. R. (1995a). "Measurement of situation awareness in dynamic systems" (*Human Factors*, 37(1), pp. 65-84).

Endsley, M. R. (1995b). "A taxonomy of situation awareness errors" in R. Fuller, N. Johnston & N. McDonald (Eds.), *Human Factors in Aviation Operations*, pp. 287-292 (Aldershot, England: Avebury Aviation, Ashgate Publishing Ltd).

Endsley, M. R. (1995c). "Toward a theory of situation awareness" (*Human Factors*, 37(1), pp. 32-64).

Hartel, C. E., Smith, K., & Prince, C. (1991, April). *Defining aircrew coordination: Searching mishaps for meaning* (paper presented at the Sixth International Symposium on Aviation Psychology, Columbus, OH).

Mann, E. (1994). *Desert storm: The first information war?*

Morton, O. (1995). *The information advantage.*

National Transportation Safety Board (1990). *Aircraft accident report: USAIR, Inc., Boeing 737-400, LaGuardia Airport, Flushing, New York, September 20, 1989* (NTSB/AAR-90-03. Washington, D.C.: Author).

Wurman, R. S. (1989). *Information Anxiety* (New York: Doubleday).

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GPSOS – GPS Occultation Sensor Tomorrow's thermometer

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In August 1997, Saab Ericsson Space received an order from the US authorities for a complete satellite-based meteorological sensor system for producing atmospheric temperature and water vapor profiles through measurements of Global Positioning System (GPS) signals. The system is called the GPS Occultation Sensor (GPSOS).

The GPSOS order was won in the face of tough international competition and is expected to lead to production spanning approximately two years. Many challenges are involved. Apart from meeting the stringent requirements of an American customer, we must be fully able to handle a new situation in which we are responsible for a complete instrument, while correctly assessing and understanding the complex requirements and keeping a demanding time schedule.

The instrument will be incorporated in a new series of American meteorological satellites, NPOESS (see accompanying box). The first series of eight satellites will utilize the radio signals transmitted from the two global satellite networks for position determination – the American GPS and its Russian counterpart, GLONASS – currently used for maritime, air and land navigation.

Today, many satellites are being launched for purposes connected with meteorology and Earth observation. In Europe, development of both Envisat and Meteosat is in progress, while the development phase of the METOP program is about to begin. In the USA, work has been in progress on NPOESS for about two years. NPOESS is intended to complement and eventually to replace the present POES satellites. In the longer term, NPOESS and METOP will be the two dominating parts of a global satellite system for meteorology and resource monitoring.

GPSOS will be installed on board the American series of NPOESS polar satellites. At the same time, plans are being developed in Europe for the METOP series, which will carry a sister instrument, GRAS. The US order is largely based on the work on GRAS instruments in which Saab Ericsson Space is already engaged on behalf of the European Space Agency.

Under the contract, we are required to determine the precision of measurement data and analyze the scientific relationships in order to assess the requirements on each part of the system. This means identifying the physical relationships, accurately describing physical phenomena and defining (specifying) the instruments and algorithms required to keep measurement errors within sufficiently narrow limits.

Saab Ericsson Space was the only company to be awarded a development contract for GPSOS. No American competitor qualified for what was originally intended to be a parallel contract.

Instrument function

The instruments for GPSOS and GRAS have the same basic method

of operation. A highly sensitive receiver on board a satellite in polar orbit measures the influence of the atmosphere on the signal from the American GPS satellite and its Russian GLONASS counterpart. By measuring the phase, amplitude and frequency of the signal, the physical characteristics of the atmosphere, such as temperature, water vapor content and electron density, can be extracted. Detailed knowledge of the position of our own satellite and that of the GPS and GLONASS satellites makes it possible to obtain very high precision in the measurements.

The physical phenomena underlying the variations in pressure, temperature and water vapor content normally occur in the lower regions of the atmosphere – the troposphere and stratosphere. A signal passing through the atmosphere will be delayed and to a certain extent dispersed. If the signal is received at the other side after passing through the atmosphere, this delay can be detected as a frequency shift. The deviation is illustrated in Figure 1. Extreme conditions may be encountered above the Equator and desert areas.

In the ionosphere, we are primarily interested in seeing how the electron density varies with altitude. It is also interesting to follow the variation throughout the day. Direct exposure to the sun leads to a considerable increase in free electrons.

We will now take a closer look at the "target", in this case an occultation. An occultation is an observation of a GPS or GLONASS signal from which we can extract information on water vapor, temperature and electron density in the atmosphere. By monitoring this signal, we can also calculate how temperature and air humidity, for

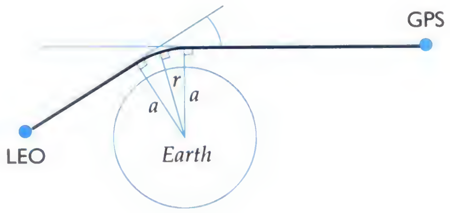

Figure 1. Atmospheric deflection of the GNSS signal.

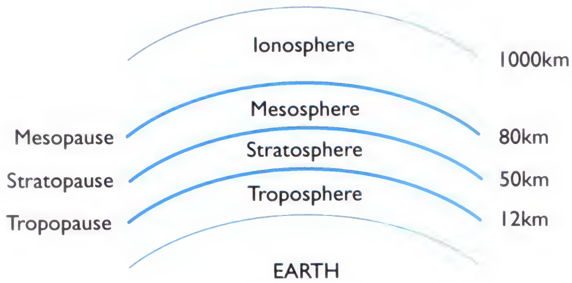

Figure 2. The various layers in the atmosphere.

example, vary within an altitude band of 2-20 km above the Earth.

The number of possible observations (occultations) is governed by the frequency with which the instrument registers a GPS or GLONASS signal, at most 1,400 times over a 24-hour period. Up to 15 signals can be received simultaneously. The duration of an observation is calculated to be about 8-12 minutes within a relatively broad sector fore and aft. The instrument's complexity is governed by the number of observations to be handled simultaneously. The number of useful observations is a concept currently being defined.

In the ongoing study, there is an interesting balance between antenna coverage and measurement quality. This includes purely practical aspects such as providing an unrestricted field of view on board the satellite without disturbance to or from other instruments.

The performance demanded of the instrument is in many ways extremely challenging. Imagine being able to determine your position with a precision of 15 meters while moving at a speed of over 1 km a second and with your reference points moving at almost 4 km a second!

Close to the Earth's surface, the water vapor content is very high and attenuation of the signal through the troposphere reaches a maximum. This requires a highly sensitive receiver to be able to make any measurements at all.

For GPSOS, it is important to measure temperature with an error of less than 1°C and water vapor with an error of less than 5 percent. The vertical band in which temperature, pressure and water vapor profiles are to be measured is from 0 to 50 km, while the band between 60 and 800 km applies to the electron density profile. The various layers of the atmosphere are shown in Figure 2.

Epilogue

At the time of writing, we have just completed the System Requirements Review, after analyzing the physical relations to clarify algorithms and primary hardware performance. Our client has expressed great satisfaction, and this has given us encouragement for further work which promises to be at least as intensive.

Efficient system work is decisive for our success. Furthermore, development of on-board instruments will involve all our areas of skill: antennas, microwave receivers, digital signal processing and instrument/interface control. This will involve extensive cooperation with our subcontractors: Austrian Aerospace (digital signal processing), Terma (software), the Danish Meteorological Institute (inter-

pretation of the physical requirements picture) and the Institute for Satellite Navigation (basic system theory). Collaboration with our Austrian colleagues is especially gratifying, as they are becoming an increasingly integrated part of our projects.

It is an inspiration to be able to contribute to generating important data for the meteorologists' work on weather models. At present, they use radio sounding devices released into the atmosphere from gas-filled balloons. GPSOS will generate far more measurements, not only simultaneously across the globe but also at lower cost. This will provide a valuable complement and stimulus to future improvements in weather forecasting.

GPS, Global Positioning System

GPS is a system of 24 satellites placed in six different polar orbits 20,182 km above the Earth, with an orbital period of 11 h 58 min. Each satellite transmits on two frequencies: 1,575 MHz (L1) and 1,227 MHz (L2). These are modulated with further information in the form of pseudo-random coded information. The codes can be deciphered by the US Defense Department with a w-code and are thereby accessible only to those using the Precise Positioning System, PPS. Without access to the codes, or "unofficial" codeless tracking techniques, it is impossible to achieve positioning to a greater accuracy than 100 m.

Information on the position of the GPS satellites and on clock errors is transmitted with a unique code for each satellite, CDMA. The time reference is related to UTC, January 6, 1980.

GLONASS, Global Orbiting Navigation Satellite System

GLONASS is the Russian counterpart to GPS and nominally comprises 24 satellites in three polar orbits, separated by an angle of 120°. The altitude is 19,100 km and the orbital period is 11 h 15 min. Each satellite transmits information on its own position and time reference, modulated on frequencies unique to the satellite (FDMA) in the 1,243-1,250 MHz and 1,598-1,607 MHz bands. Information from GLONASS is also coded, but with the difference that the precision code is known, which permits higher accuracy in determining orbital position.

NPOESS, National Polar-orbiting Operational Environmental Satellite System

NPOESS is a US national program designed to develop and establish the next generation of systems for acquisition of global resource and meteorology data. Initially, 12-14 instruments have been identified which will be available for integration on the satellite platform. Six of these, among them GPSOS, have been chosen for more detailed study in a risk-reduction phase of the project. This involves placing parallel contracts and carrying out mission and realization studies lasting one to two years, depending on instrument complexity. The phase will conclude with a final choice of instrument supplier in December 1998.

NPOESS is intended to comprise three satellites operating simultaneously, at least two of which are of the American NPOESS type while the third may be one of Eumetsat's METOP series. These will be placed in a Sun-synchronous polar orbit at a nominal altitude of 833 km and an inclination of 98.7°. The orbital period will be 102 min, or 14.2 orbits per day.

Space equipment in serial production. During the year, Space delivered 1,000 antenna elements for satellite-borne mobile telephony to Hughes Space and Communications in the USA. Altogether the order comprises 3,100 antenna elements for 12 satellites. →

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Human-Centered Design in Aviation Technology

Dr. Chris Wickens is Professor of Psychology and Head of the Aviation Research Laboratory at the University of Illinois Institute of Aviation. Dr. Wickens is an internationally recognized research scientist in the area of aviation psychology. He has authored or edited books on engineering psychology, mental workload, human factors, human factors in air traffic control, and aviation displays. He is the author of more than 100 scientific publications in the area of human factors and aviation psychology. He is an elected member of the Society of Experimental Psychologists, a Fellow of the Human Factors and Ergonomics Society, and a Fellow of the American Psychological Association, division of engineering and applied experimental psychology, where he was awarded the Franklin F. Taylor award for outstanding contributions. His expertise lies in display design.

Introduction

Advances in technology have brought about a great number of improvements to both the efficiency and safety of aviation. At the same time, it is imperative that such technology be introduced with sensitivity to the capabilities (strengths and limitations) of both pilots and air traffic controllers. This sensitivity is the domain of aviation human factors. A human factors approach must also be carefully guided by empirical data collection from pilots and controllers performing tasks in controlled experimental conditions. In order to illustrate for you the relevance of the human factors approach.

I would like today to briefly outline one concept of the pilot as an information processing system and then describe how three aspects of increasingly sophisticated automation technology can impact both positively and negatively on the pilot's performance. These are represented by the head-up display, the electronic map and the automation of control or decision functions. Figure 1 shows a very simplified view of the pilot as an information processing system.

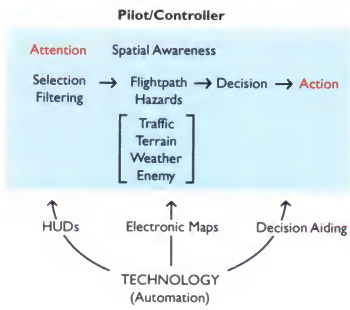

Figure 1: Schematic representation of pilot/controller as an information processing system.

The pilot must first selectively *attend* to the rich world of information channels, processing what is relevant and filtering the irrelevant. The pilot may also need to divide attention between different sources of relevant information. The filtered information thus attended and perceived must then be interpreted in terms of its three-dimensional spatial relevance; assessing where flight must proceed and, equally important, assessing the location of hazards such as weather, terrain and traffic, or hostile areas that the flight path must avoid. This we refer to as spatial hazard awareness. Based on such an assessment, decisions of actions are made, and the actions are then executed to turn, accelerate, continue, etc. As the figure shows, at all phases of information processing, there are tasks and operations which the technology of automation may assist, if it is properly implemented; these are also tasks that automation may disrupt, if care is not given to following human factors guidelines for human-centered technology.

The Head-Up Display

The simplest level of technology we consider is the head-up display (HUD). The primary goal of the HUD is to facilitate the allocation of visual attention between two domains of information (Figure 2): the near domain of the instrument panel, and the far domain of the world outside the aircraft (Weintraub and Ensing, 1992).

Thus with a HUD, the pilot does not need to look downward to see the instruments, but can perceive those instruments superimposed on the far-domain view of traffic and ground features. There is a reduced area to scan, and the HUD can sometimes facilitate the division of attention between the near and far domain, as when the HUD indicates the location of a far-domain element like a runway. Yet the clutter produced by these over-

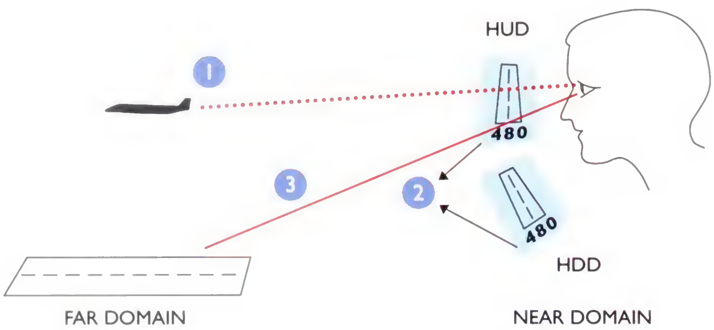

Figure 2: Information domains in a head-up display (HUD) vs. head-down display (HDD)

lapping images can disrupt the ability to focus attention.

The HUD is a concept that has been well validated to improve many aspects of pilot performance in both military and civilian aviation. However, human factors research has helped to identify both strengths and weaknesses of the technology (Wickens, 1997a). In terms of its strengths, the HUD has been found to work best if the symbology is conformal with features of the outside world, overlaying those features and moving in synchrony with them as the aircraft moves through space. Examples of conformal symbology are a horizon line, a runway overlay, a velocity vector, or a flight path tunnel or "highway in the sky". In contrast, the weaknesses of HUDs emerge when too much non-conformal information is presented, creating clutter which can harm the focus of attention on information in the far domain. Of particular concern, a cluttered HUD can disrupt the detection of critical unexpected elements in the far domain, such as an intruding aircraft unexpectedly moving on to the landing runway, requiring a missed approach (Wickens and Long, 1995). Thus, human factors can offer guidelines on the use of this technology in helping to resolve the tradeoff between scanning and clutter.

Electronic Maps

There is little doubt that the development of electronic maps, which can present a dynamic representation of the pilot's current position in reference to the flight path and to hazards, has been of great benefit to air safety. Indeed, continued development of the Enhanced Ground Proximity Warning System, with its depiction of threatening terrain, should provide critical guidance in helping to reduce the recent number of tragic CFIT, or Controlled Flight Into Terrain, accidents.

Yet precisely how electronic maps should be implemented remains a critical issue that must be addressed by human factors research. For example, should the map rotate in the direction of travel to remain "track up" or remain fixed in a north-up mode? Our research suggests that it should rotate in order to eliminate the need for the pilot to mentally rotate the map image when flying south.

Should maps integrate or overlay information from different data bases, like traffic and weather, or present such data bases in separate frames to avoid clutter. Here human factors research clearly indicates that integrated representation is better in spite of the costs of clutter (Merwin *et al.*, 1997).

A third issue is whether electronic maps should present spatial information in the same planar or "2D" format as the conventional paper map, or whether they should capitalize upon new graphics technology to present a "3D" world? Here the answer is considerably more complex and has only emerged from a great deal of human factors research.

It turns out that for a map portraying the desired flight path, the integrated 3D "tunnel in the sky" appears to be a very valuable design innovation (Theunissen, 1995) that is clearly superior to the 2D plan view representation of flight guidance (Wickens, 1997b). This is because the tunnel integrates the lateral, vertical and longitudinal axes of the forward flight path in a single panel, thereby reducing scanning. The 3D map is also superior for navigation in low-level visual contact flight.

However, for maps that portray hazards in the air (other traffic, weather), the results of human factors research are far less promising for 3D technology. The benefits of 3D displays in integrating several axes appear to be dominated by two critical costs. First, 3D displays provide a privileged or "keyhole" view of some parts of the world at the expense of others, which are behind the viewpoint. Hence, critical hazards may not be viewable. While some of these hazards may be brought into the display by broadening the geometric field of view, this solution is not satisfactory because of the distortions it produces in where objects appear (McGreevy and Ellis, 1986; Wickens and Prevett, 1995). Second, 3D displays represent positions in a 3D volume of space as points on a 2D viewing surface. This creates a serious ambiguity along the viewing axis, which can critically affect the pilot's judgements of where things are in 3D space. Together, these deficits of 3D displays are very hard to overcome, relative to 2D or coplanar counterparts that depict both lateral and vertical dimensions of the airspace in undistorted planes.

So, here again, knowledge of human factors has helped to guide designers not only on the values, but also the limitations of advanced technology.

The first two applications of technology that I have discussed have focused on the perception and understanding of flight information. For my third application, I consider more broadly the issue of the general application of automated technology to aid

all aspects of pilot and air traffic controller performance.

First, we note that automation, on the flight deck or on the ground, is not a single entity. Indeed, investigators often speak of several levels of automation; but we go a step further to distinguish between two important *dimensions* of automation, each of which has several levels, a distinction that is critical in terms of the human factors of its implementation (Figure 3, opposite).

On the one hand, automation of information gathering and integration refers to the use of computers to perform a number of functions like data gathering, data filtering, state estimation, changing display configuration and prediction. The more of such features are present, the higher is the level of information-gathering automation. As we discussed earlier, well designed electronic maps represent an excellent example of the good, or "human-centered", application of such automation. If it is carefully designed, with attention to user need and to the cognitive factors involved in display interpretation, and if the depicted information is reliable, then such automation provides strong benefits in improving situation awareness of the pilot or controller (Endsley, 1995).

But computers can also contribute to levels of automation in the selection and execution of actions. As shown across the bottom of the figure, a computer may *recommend* several actions, may recommend only a few actions, or only one. It may select an action and carry it out *if* the operator approves, or it may carry it out automatically *unless* the operator *vetoes* the action. Our synthesis of the literature on automation suggests that these higher levels of action automation are

Figure 3: Levels of automation in information integration and action selection.

not necessarily good, and should be adopted only with extreme caution. Why is this so? Because if the automation generally works successfully, humans will come to rely on and trust it more than they should – we refer to this phenomenon as *complacency*. The better the automation works, the greater is the trust and the more complacent the operator will become (Parasuraman and Riley, 1997). Then, if the automation should ever fail to perform its function in a manner expected by the operator, who is now a supervisory monitor, human factors research has revealed that such complacency can lead to serious, and sometimes disastrous, consequences. It will cause detection of the failure to be slower, understanding of the nature of the failure to be poorer (degraded situation awareness), and will cause intervention with manual skills to be slower and sometimes less appropriate. So designers must resist the temptation to push for high levels of automation of control action even as they may do so for information acquisition. Hence, the "region" of the space that should be developed most enthusiastically is the upper left of Figure 3.

In conclusion then, advanced technology has provided tremendous benefits to air safety; but these benefits can be maximized only if the technology is harnessed with a clear understanding of the human user. Human factors has provided a research methodology that can address the tradeoffs in human performance presented by technology: clutter vs. divided attention in the case of HUDs, integration vs. ambiguity for 3D, and automation of information acquisition vs. control. As I have learned about Saab Aerospace, and its link with Linköping University and the Swedish Center for Human Factors in Aviation, I am delighted to see this approach so well represented in your company, and I am privileged to join with you in this wonderful celebration.

References

Endsley, M.R. (1995). "Toward a theory of situation awareness in dynamic systems" (*Human Factors*, 37(1), pp. 85-104).

McGreevy, M.W., and Ellis, S.R. (1986). "The effect of perspective geometry on judged direction in spatial information instruments" (*Human Factors*, 28, pp. 439-456).

Merwin, D., O'Brien, J.V., and Wickens, C.D. (1997). "Perspective and coplanar representation of air traffic: Implications for conflict and weather avoidance" (*Proceedings of the 9th International Symposium on Aviation Psychology*. Columbus, OH: Dept. of Aerospace Engineering, Applied Mechanics, and Aviation, Ohio State University).

Theunissen, E. (1995). "Influence of error gain and position prediction on tracking performance and control activity with perspective flight path displays" (*Air Traffic Control Quarterly*, 3(2), pp. 95-116).

Weintraub, D.J., and Ensing, M.J. (1992). *Human factors issues in head-up display design: The book of HUD* (SOAR CSERIAC State of the Art Report 92-2. Dayton, OH: Crew System Ergonomics Information Analysis Center, Wright-Patterson Air Force Base).

Wickens, C.D. (1997a). "Attentional issues in head-up displays" (in D. Harris (Ed.), *Engineering psychology and cognitive ergonomics: Integration of theory and application*. London: Avebury Technical Pub. Co.).

Wickens, C.D. (1997b). "Frame of reference for navigation" (in D. Gopher and A. Koriat (Eds.), *Attention and performance, Vol. 16*. Orlando, FL: Academic Press).

Wickens, C.D., and Long, J. (1995). "Object- vs. space-based models of visual attention: Implications for the design of head-up displays" (*Journal of Experimental Psychology: Applied*, 1(3), pp. 179-194).

Wickens, C.D., Mavor, A.S., and McGee, J. P. (Eds.) (1997). *Flight to the future: Human factors in air traffic control* (Washington, DC: National Academy Press).

Wickens, C.D., and Prevett, T. (1995). "Exploring the dimensions of egocentricity in aircraft navigation displays" (*Journal of Experimental Psychology: Applied*, 1(2), pp. 110-135).

Saab Systems at the Frontiers of Technology

by Billy Fredriksson
Saab AB, Linköping, Sweden

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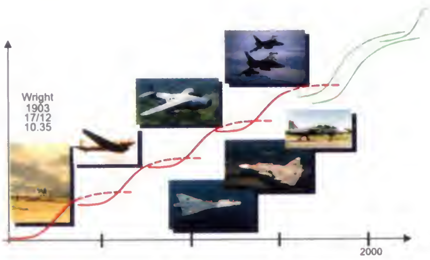
Man-Machine Interfaces
The Heart of Systems Integration

Before the Wright brothers achieved fame in December 1903, there had already been many attempts to perform controlled flights. During the century that followed, we have witnessed tremendous technological advances in the field of aviation. While yesterday's pilots certainly operated in a demanding environment, they would not recognize the challenges of man-machine integration faced by today's aviators.



New technologies and the S-curve

With the arrival of new technologies, aviation and a host of other disciplines have developed high-performance systems combining physical performance with built-in knowledge and intelligence. Such systems are the result of the integration of mechanics, electronics, computers and software. The man-machine interface disciplines and human factors-related technologies are of primary importance to Saab as a systems integrator in aerospace and defense, since these disciplines are at the heart of integration.

New Technologies, New Challenges

During the 60 years that have passed since it was founded in 1937, Saab has been a pioneer both in the development and the use of new technologies. Each technological advance meant new challenges for the human factors and human-machine interfaces. Indeed, the ability to take on new technologies at the right time has been a central factor in Saab's ability to maintain its competitive advantage.

An early challenge came in 1943 with the introduction of the Saab 21 fighter, an aircraft with a pusher propeller. One of the difficulties faced by engineers was to develop a safe pilot escape system. This effort culminated in Saab's successful pioneering of the ejection seat.

Next came the Saab 29, also known as the Flying Barrel, which was first flown in 1948. This was one of the very first aircraft with a swept wing. With its 25° sweep came new aerodynamic phenomena that resulted in new flying characteristics related to handling qualities.

In 1955, the supersonic Saab 35 Draken was the first double-delta wing aircraft with high lift and turning performance. The wing configuration also introduced new aerodynamic phenomena, which for example resulted in super-stall characteristics. Accordingly, new training schemes had to be developed for all air force pilots.

The success of the Draken enabled Saab to produce 604 of these aircraft. A number of human factors-related technologies were developed. For example, the two-seater version has a side airbag for safe escape from the rear seat. Furthermore, a new ejection seat was developed and tested for use at supersonic speed. At present, the Draken is still used for tactical missions by some air forces and for pilot training at the National Test Pilot School in the United States.

The Saab 37 Viggen, first flown in 1967, was pioneering in several new technologies. To illustrate, there was the innovative aerodynamic configuration with its close-coupled canard delta wing. This feature provided the aircraft with high-lift performance at low speeds, making it suitable for operation from dispersed road bases. The

CONTINUED ON PAGE 26

new aerodynamic characteristics brought about the development of a new flight control system for good flying qualities. This was also the first aircraft equipped with a central digital computer and autopilot. Furthermore, with its datalink and computer capacity, the Saab 37 Viggen could be considered one of the first systems aircraft.

Defense and aerospace scenarios

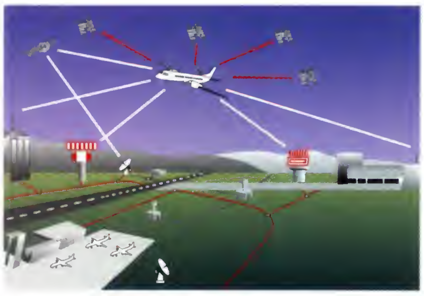
Rapid developments in electronics, computers and sensors, and the capabilities to integrate these hardware and software technologies, have transformed both the civil and defense scenarios.

Information technology warfare

In the area of defense, for example, the Gulf War showed how prevalent and important information technology warfare had become, (i.e. information acquisition and the utilization of high-precision weapons). Accordingly, space, air, land and sea forces had to be integrated. Continued development in this direction will, on many levels, change the requirements on man-machine interfaces as well as on the operation of such systems.

Similar scenarios also exist within the civil arena.

There, area-watch systems will be used for safety and rescue, security and environmental protection, as well as for land and maritime traffic control. In commercial aviation, air traffic management and control already use these new technologies to facilitate higher efficiency and safety.



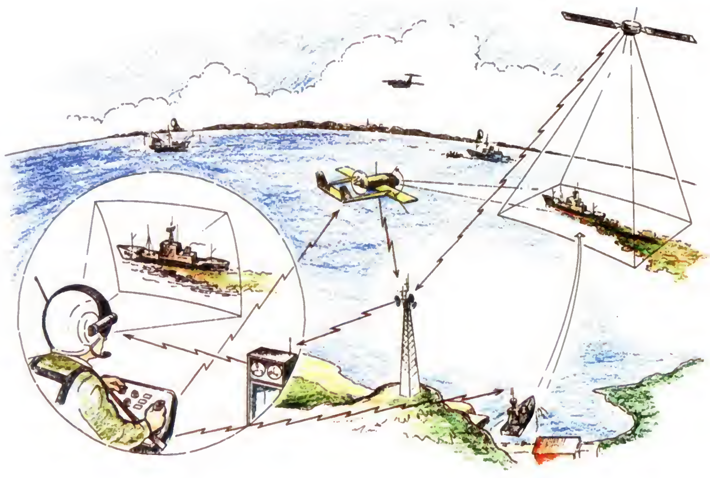
A commercial air traffic control scenario

Saab entered the civil aircraft business with the Saab Scandia, first flown in 1946. Given the technologies available at that time, this was a rather demanding environment to fly in. Saab exited this market in the early 1950s, concentrating solely on manufacturing military aircraft for the next 30 years. In 1980, we returned to the civil aircraft business with the development of the Saab 340.

By the early 1990s, Saab had successfully integrated the latest human factor-related technologies in the Saab 2000. For example, there is a modern glass cockpit with color displays, crew alerting systems, decision support and built-in intelligence, plus an ergonomic layout of the cockpit. A head-up display is also available. All of these features make for an efficient and safe working environment.

Studies have shown that seat-mile efficiency has increased two and one half times over the past 50 years. Eighty percent of this improvement can be attributed to developments in propulsion technology, while changes in aerodynamics and structures have contributed 20 percent. Furthermore, changes in cockpit design have reduced crew size from four or five persons in the 1950s to just two in 1997, even for large aircraft. Demands for increased efficiency are now focused on air traffic control to improve communication management and control for shorter flight routes and by reducing time in holding positions while still maintaining high safety levels.

With pressure from the market as the driving force, other changes in the civil aviation arena will certainly include the incorporation of such technologies as GPS and new sensor technology. Already in 1988 Håkan Lans´s differential GPS technology was tested in a Saab 340. These technologies will be central to the efficiency of air traffic management and the ability to maintain safety standards as the number of aircraft in use more than doubles over the next 20 years (according to market research). Thus, new man-machine interfaces will be required. Finally, these new technologies will also include the development of systems to avoid ground collision as well as systems for crew resource management, etc.

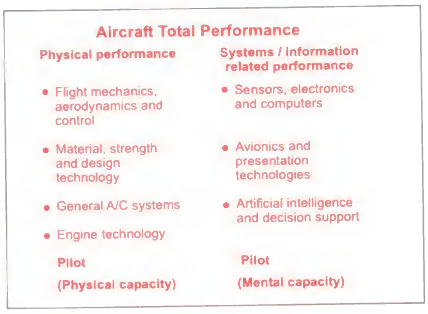


A civil area-watch scenario

Total performance of systems

The total performance of a system includes both the physical performance and the systems- or information-related performance. Let me take an aircraft system as an example. The physical performance is generated by the efficiency of the propulsion system, flight mechanics, aerodynamics

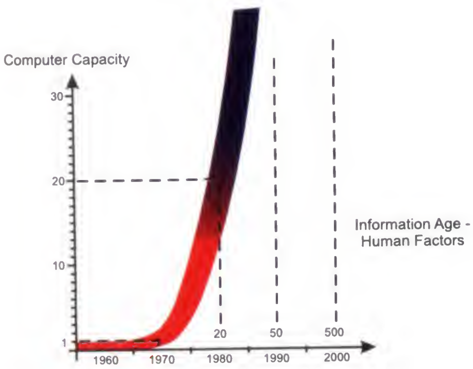
and control, as well as by the strength of the materials themselves. It is limited by the pilot's physical capacity, taking into account possible protection systems like G-suits.



Example of system performance parameters

The systems- or information-related performance is generated by electronics and computers, sensor technologies, and the tactical and avionics systems (including artificial intelligence and decision support). This performance is limited by the pilot's mental capacity. The designers' challenge is to create systems that support the operator in the best possible way in the physically and mentally demanding environment.

It is interesting to study the development of on-board computer capacity in aircraft systems.



Computer capacity and the information age

In terms of computing speed, memory or number of CPUs, there was a rapid development of information technology during the late 1970s and the 1980s. During this period, Saab entered the information age with the development of the first systems aircraft, the 37 Viggen.

Increased computer capacity has also been the driving force for new knowledge on human factors related to the mental capacity of the operator. Information technologies and new sensor technologies have made it possible to develop systems for collecting, processing and presenting information about complete situations. The challenge remains to develop efficient systems that enable the operator to achieve maximum situation awareness, thereby making the best possible decisions in physically and mentally stressful situations. These developments illustrate the interdisciplinary nature of man-machine integration/interfaces, with solutions derived from such fields as physiology, ergonomics, psychology, behavioral and cognitive sciences.

The defense scenario

I will now return to the defense scenario to provide a more detailed examination of the interaction between human factors (both physical and mental) and the man-machine interfaces. With this example, I will discuss two subsystems existing within a larger hierarchy of systems. At a higher level in the hierarchy there is the operator in the command-and-control center. In the other subsystem, at a lower level in the hierarchy, there is the vehicle operator (in the air, on land or at sea). I will be discussing the technologies relevant to these subsystems.

Using space and sensor technologies it is possible to generate geographic and topographic information for precise positioning and the generation of detailed virtual-reality databases. Furthermore, planned low-orbit satellite projects like the Teledesic program make global broadband multimedia communication possible.

New sensor technologies provide information on the complete scenario on land and in the air. For example, airborne early warning systems or unmanned aerial vehicles (useful for deep penetration to areas of high risk) provide continuous situational information. Silent information acquisition is possible using passive infrared search and track sensors.

Infrared search and track sensor application

These technologies provide massive quantities of information both to the command-and-control center operator and to the vehicle operator. This information is used for battles beyond visual range and for physically demanding close combat scenarios. Accordingly, new knowledge related to the operator's physical and mental capacity is required (especially regarding the operator of the airborne vehicle).

Modern aircraft like the Gripen are developed for loading as high as 9G. Utilization of thrust-vector control technology increases aircraft agility even more.

The Gripen Aircraft

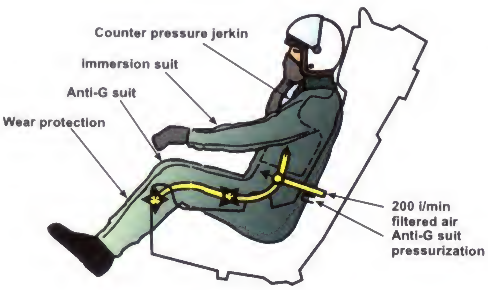
The Gripen was developed to meet the requirements for this combined information-warfare and close-combat defense scenario. It is the first aircraft to be defined as fourth-generation. As such, the Gripen is a multirole systems aircraft incorporating many new technologies, such as many important electronic and computer breakthroughs that were mentioned earlier.

Technical challenges in developing the Gripen

The challenges that had to be met during the development of Gripen derived from the requirements for

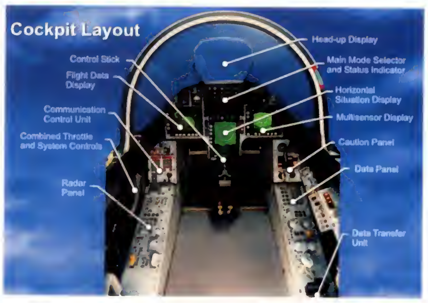
multirole capability, 9G maneuvering performance, small size, light weight, and simplicity and ease of operation with the capacity for autonomous operations from dispersed road bases. To be efficient in the complex warfare scenario that I described earlier, the aircraft was designed with the flexibility to adapt to new tactical requirements and to incorporate future technologies. This is possible thanks to computer hardware and software solutions as well as a high degree of integration. Furthermore, the digital flight control system supports the pilot in flying the aircraft. This enables the pilot to concentrate on the main task, that is making optimal decisions and taking the best possible action in fighter, attack or reconnaissance roles.

The Gripen could, in many senses, be described as a "high-density" aircraft. It utilizes a large variety of materials and structures, it has densely packed mechanical and electronic systems, and a high density of information. All these requirements and new technologies have meant new challenges relating to human factors.



The Gripen tactical flight combat suit

The physical and mental workload has driven the development of physical protection systems such as the tactical flight combat suit. Furthermore, the aircraft is equipped with an airbag in the rear of the two-seat aircraft to protect the pilot.



The Gripen cockpit layout

The cockpit layout and the tactical systems were designed to support high information content and situation awareness. For example, the hands-on-throttle-and-stick (or HOTAS) system enables the pilot to concentrate on information provided by the three head-down displays (flight data, horizontal situation and multi-sensor) as well as the large head-up display. By simply pressing a button, the pilot can change the system to fighter, attack or reconnaissance configuration.

Training

The importance of operator training for civil and defense scenarios with such advanced systems as those already described cannot be underestimated. In order to be most effective, training should be such that operators learn by direct experience. Furthermore, learning in an appropriate environment impacts one's ability to recall and utilize new knowledge. Finally, it is important to train operators in groups, as modern advanced systems mostly rely on teamwork.

Given the time and resources required, utilizing such advanced systems is very costly. By using modern

information technology and sensors, however, it is possible to develop simulators that both save time and significantly reduce the cost of training. Simulators can also be an efficient means of introducing new technologies and tactics. As such, they could be considered as "strategic change tools".

Saab Training Systems has developed unique capabilities in simulation and training, and currently manufactures high-quality simulators for the battlefield. These systems allow for pre-planning and post- analysis, both of which are very important to the overall effectiveness of the training exercise.

For the Gripen system, Saab and the Swedish Air Force, in particular, have spent a lot of effort developing training systems and training programs. At Saab we have a number of development simulators that can be used for training purposes. The Air Force has invested in an extensive resource for simulation and training at the F7 Wing in Såtenäs.

One important category of systems for efficient utilization of modern advanced systems is engagement and mission planning systems. Here, user interfaces play an important role in both pre-planning and particularly post-engagement and mission analysis.

Systems preparation and maintenance

In combat situations, advanced systems must have the flexibility to adapt to new tactical requirements and allow for a quick turn-around for new missions. Accordingly, the Gripen is equipped with a system that allows for a complete turn-around in less than 10 minutes, using just one technician and five conscripts.

The Gripen is a very small aircraft with densely packed systems. To allow for efficient maintenance, the aircraft was designed to support ease of assembly and disassembly. Accordingly, three-dimensional computer-aided design was an important simulation tool during the design phase.

The Development Process Methods and Tools

Advanced development tools are required to develop such systems where man-machine interfaces are of primary importance. Following our modelling concept that is used in product development, we have developed a process that is supported by advanced tools for the systems development.

First, using models of aircraft, weapon systems, countermeasures systems, etc., we can make tactical simulations of different scenarios. Also, the virtual front panel allows for simulating different functions and displaying new symbols. Furthermore, mission and operation analysis, as well as air combat simulation, are now possible. These activities are coupled to our dome simulator where we can perform functional simulations and flying missions in the virtual terrain. When a new function is implemented in the aircraft system, it is verified in the different system simulators before being verified in an actual flight test.

Research

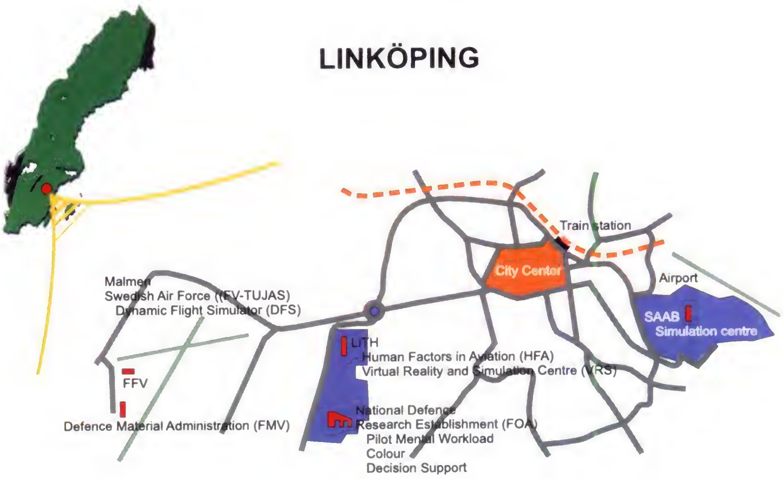
The tools and simulators just described are also used for research. As mentioned earlier, the studies of man-machine interfaces must draw upon research from many different scientific disciplines in order to make significant advances. At Saab, there is heavy emphasis on co-operation with the research community. This includes various universities, research institutes and of course the Swedish Air Force and Air Materiel Administration. In this interdisciplinary environment, it is important to take a long-term approach in order to acquire new knowledge and effectively implement new technologies.

The dynamic flight simulator

In Sweden, the importance of research into man-machine related sciences is well understood and accordingly a great deal of investment in this area has been made in recent years, both in the civil and the military communities. Many resources are now available or under construction. I would especially like to mention the dynamic flight simulator, currently under construction at the Defence Materiel Administration Test Department in Malmslätt, Linköping. This is a unique facility with a combined simulator and centrifuge that allows us to study operator capacity under both physical and mental loading.

Other examples are Linköping University's National Center for Human Factors in Aviation and Virtual Reality Center.

A helmet-mounted display system



Human factors-related resources in Linköping

At Saab, we have invested in a number of different simulators, the most recent being the advanced dome simulator mentioned earlier. Indeed, Saab is very fortunate already to have many research activities in human factors concentrated in and around Linköping.

This situation has now improved even more with the Swedish Defense Research Establishment deciding to concentrate its main activities in human factors research in Linköping. All of this facilitates an excellent environment for co-operation in human factors research.

New research programs have also been started in Sweden. First, there is the Swedish Air Force's "Human in the Flight System" military program. The other is the Graduate Research School in Human-Machine Interaction, which is supported by the Foundation for Strategic Research. Research is also performed within the national aeronautical research program.

At Saab, research is ongoing in many different areas and I would like to mention some of them. We are conducting research into:

- Decision support for pilots; and
- Display design and information allocation;
- Design of the auditory environment including three-dimensional audio displays and direct voice input;
- Cognitive complexity;
- Methodology for the assessment of mental and physical workload/ performance and situation awareness;
- Visual interaction and human effectiveness in the cockpit. Figure below shows an application where

infrared technology, video cameras and electromagnetic field measurements are used for gaze-tracking, workload measurements and situation awareness in the Saab 2000 simulator.

Research into visual interaction and human effectiveness in the cockpit

Another interesting new technology that we are investigating is the virtual retinal display technology developed by Microvision in the United States. This is a low-energy laser technology where the images are generated directly on the retina in the eye. This opens up a series of interesting applications in both civil and military fields.

With our present technology and competence, along with appropriate short- and long-term planning, we at Saab believe that we can keep up with the state of the art and continue to develop advanced, highly competitive products for operation in the increasingly demanding environment of the future.

Saab professorship established at Chalmers

Rapid developments in electronics, computer and software technology, sensors and their integration with mechanical systems mean that today's – and especially tomorrow's – systems are becoming more advanced and complex.

Special requirements for reliability, robustness and fault-tolerance are being made, especially on real-time systems. This is a very important area for the majority of units in the Saab Group and it has therefore been decided to find ways to support and reinforce new, stronger research methods. Discussions with Chalmers University of Technology in Sweden have now resulted in the decision to support, together with Saab Automobile AB in Trollhättan, establishment of the Saab professorship in Reliable and Robust Real-Time Systems at Chalmers.

The new professorship will be financed for a period of five years by Saab, Saab Ericsson Space and Saab Automobile, and will involve a total of SEK 15 million. The agreement between these companies and Chalmers was signed on 8 December 1997. The Chalmers professorship will cover the area of reliable and robust real-time systems and encompass reliability, robustness and fault-tolerance in integrated real-time systems. These consist of computers, software, electronics and mechanics as well as systems which may contain digital and/or analogue parts.

This is an example of a long-term investment in a top-priority area, made possible by internal teamwork at the Saab Group as well as external co-operation. We are particularly pleased to be working with Saab Automobile.

Through this project, research is also being supported which could lead to industrial applications in the space, aircraft and automobile industries, as well as other advanced systems areas at the Saab Group. This should guarantee a solid research base at Chalmers.

"We hope that this will contribute to the Saab Group's long-term supply of expertise and that it will result in valuable research projects and industrial postgraduate studies at the Saab Group's units," says Dr. Billy Fredriksson, Vice President, Corporate Technology.

"Chalmers is building up skills and expertise within a sector relevant to our industry," says Bengt Halse, President and CEO of Saab. "Today, great demands are placed on the technological development of durable products and systems for which there is a demand, and which can be developed and produced. It is important to support this area of research, since it is closely connected to our areas of operations and may in the long term provide us with the necessary pioneering expertise."

"Chalmers is very pleased to be involved in this project. It strengthens and complements important research being conducted in the systems-technical area," says Anders Sjöberg, Dean of Chalmers.

"The number and scope of applications for computer and electronic systems are increasing in the space area," says Ivan Öfverholm, Managing Director of Saab Ericsson Space. "These systems are becoming increasingly complex, at the same time as demands for reliability are increasing. We are determined to strengthen and build on the skills we have in the area of fault-tolerant computers. The newly established professorship will be an important research resource."

"The development pace in car electronics is extremely rapid and we expect growth in many areas regarding safety aspects," says Stig-Göran Larsson, Deputy Managing Director of Saab Automobile. "This requires knowledge about fault-resistance and reliability, not only for steering-related electronics but also for the mechanical systems served by the electronics. The forthcoming professorship will be a major asset in our future development projects."

Saab NILS – a new landing system for the Gripen

When a replacement had to be found for the present landing system used by the Swedish Air Force, the concept of an autonomous landing system was proposed. This is a flexible solution which employs only the existing sensors in the aircraft. A further advantage is the considerable saving, since the need for an expensive ground infrastructure is eliminated and there is more room in the aircraft for other equipment. Saab AB, Gripen, and Saab Dynamics AB were jointly commissioned to develop the new landing system.

Development of the new navigation and landing system for the Gripen has recently been started in Linköping. Unlike the existing landing system, which requires an infrastructure, the new system will enable the Gripen to land without any assistance from the ground, even in poor weather. This conforms well with the Swedish Air Force strategy of using road bases and a geographically widely dispersed system for aircraft turnaround. With the introduction of NILS (New Integrated Landing System), CAT I landings can be made on almost any runway. CAT I landings mean that the pilot must have the runway in sight at a height of no less than 60 m in order to complete a landing.

Apart from the fact that NILS itself is unique, work is also being carried out in a way that is somewhat unusual for Saab. The project participants come from Saab AB Gripen and Saab Dynamics AB. The two companies have assembled a team of highly qualified engineers working closely together without regard to the fact that they formally belong to two separate organizations. During the pilot study phase, which has been in progress for 18 months as an R&D program, this form of collaboration has proved very satisfactory and the foundations have now been laid for NILS. This success is probably due to the mix of young engineers with fresh knowledge from university, experienced engineers, engineers trained in research, and excellent contacts with Linköping Institute of Technology.

NILS is funded by the Defence Materiel Administration (FMV).

by Predrag Pucar
Saab AB, Gripen

Dr. Pedrag Pucar is in the Primary Flight Data and Navigation department at Saab AB Gripen. He has a Ph.D in automatic control from Linköping Institute of Technology. The work presented in his doctoral thesis is in the field of model-based signal processing and modeling of non-linear systems. At the (then) Saab Military Aircraft division, he worked on studies that led to an established concept for decentralized sensor fusion in target tracking. He is currently fully involved in the NINS/NILS project.

TECHNICAL DESCRIPTION

The new landing system represents Stage 2 in a major development project. Stage 1 is the development of a navigation system sufficiently accurate to be used as the basis for a landing system. A high-performance navigation system also opens up possibilities for many applications other than landing. Test flights with an experimental module in the Saab 105 trainer (also known as the Sk60) have already started.

New integrated navigation system

NINS is an aircraft autonomous navigation system, i.e. it needs no information from outside the aircraft. However, the system must be able to utilize external information when available. NINS is based on applying advanced data fusion to a number of different information sources. These are:

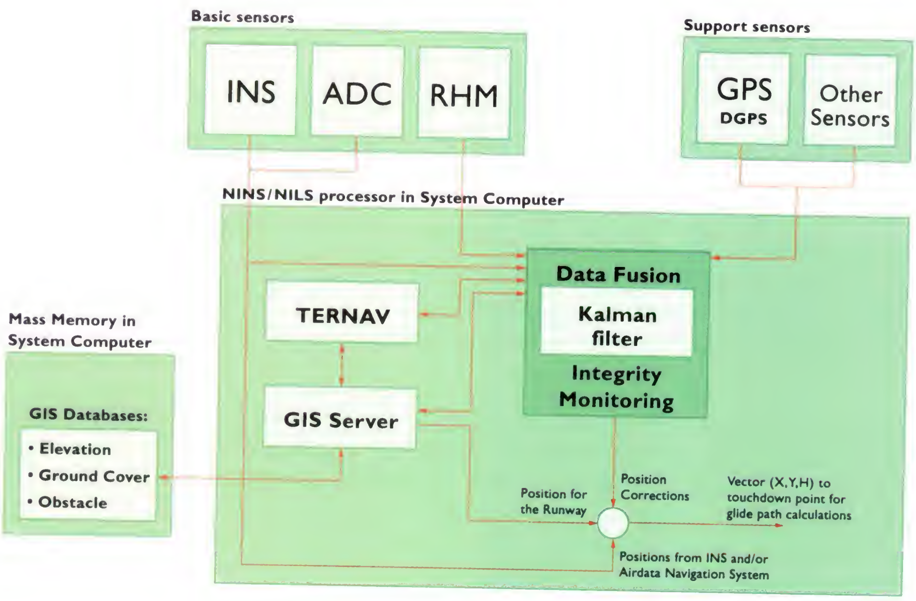
RADAR ALTIMETER. Currently installed in the aircraft and used in NINS for measuring distance between aircraft and ground.

TERRAIN DATABASE. The Gripen will carry three databases with varying types of information content. The largest database is an elevation map of the whole of Sweden based on a grid with an internode spacing of 50 meters. Altitude above sea level for each node has then been stored in the database. The second database is a terrain cover map describing the type of terrain (dense forest, sparse forest, fields, etc.) at a particular coordinate. The third database contains all man-made obstacles in Sweden, such as TV masts.

AIR DATA SENSOR. This sensor is one of the most important in the aircraft system since it provides the pilot and the flight control system with information on speed and altitude. The altitude is expressed as the height above a pressure surface, such as the sea.

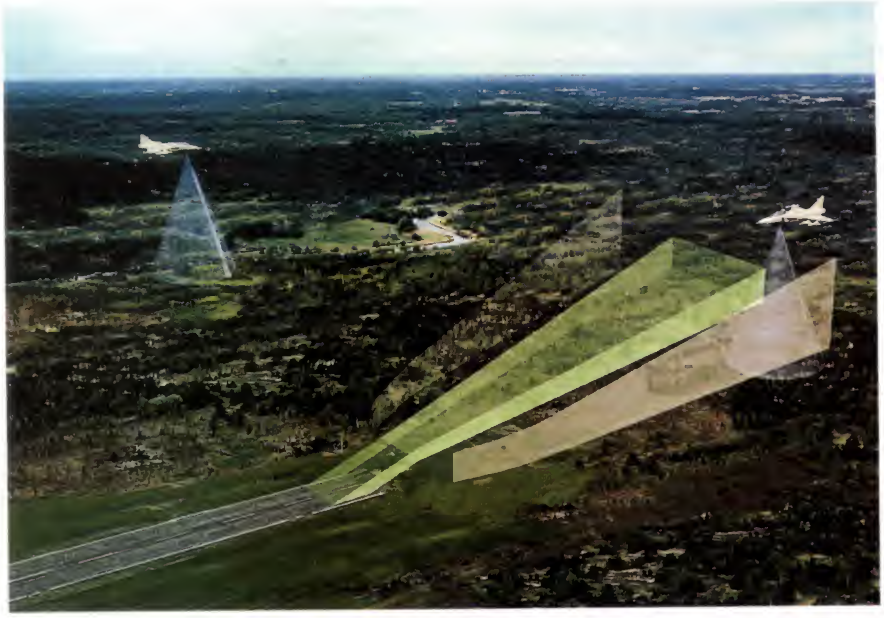
INERTIAL NAVIGATION SYSTEM (INS). This will continue to be the central sensor in the Gripen. It comprises a set of accelerometers and gyros measuring aircraft acceleration and angular velocity. Since the take-off coordinates are known, it is possible to make a dead-reckoning of aircraft position. The advantage of INS is that it is possible to measure extremely highly dynamic maneuvers, while the disadvantage is that it is subject to gradual drift owing to imperfections in the sensors.

These are the sensors forming the basis for NINS. The first three information sources are used for calculating aircraft position with a terrain navigation algorithm, Saab TERNAV, a complex and highly non-linear data fusion algorithm developed by Saab Dynamics. The initial version of TERNAV has already been installed in an AJ37 Viggen and has proved very successful in operation. Two things distinguish the TERNAV that will be installed in the Gripen. The Gripen variant is a development of TERNAV adopting ideas from advanced target-tracking algorithms with parallel filters. The other difference is that TERNAV in the Gripen is fully integrated with other sensors, unlike the Viggen solution where it performs the same function as a normal pilot fix, i.e. the position from INS is corrected using TERNAV data, but no calculations of sensor errors are made. NINS uses state-space modeling (a method of representing the differential equations applying to the system) and an



INS: Inertial Navigation System
ADC: Air Data Computer
RHM: Radar Altimeter
GPS: Global Positioning System
PPS: Precise Positioning Service
DGPS: Differential GPS
TERNAV: Terrain Referenced Navigation
GIS: Geographical Information System
NINS: New Integrated Navigation System
NILS: New Integrated Landning System

NINS/NILS System Block Diagram for JAS 39 Gripen



Saab NILS – the landing system of the 21st century

extended Kalman filter to integrate the information. The architecture of the Gripen system is shown in the accompanying diagram.

Apart from the sensors contained in the basic system, support from GPS and other aids can be used for further enhancing system performance.

A new integrated landing system

The future landing system for the Gripen is based on the navigation system already described. There are primarily two characteristics that are important: accurate position information and awareness of system performance. The latter is additional in an application that is critical for flight safety, such as landing. Monitoring to ensure that actual system performance is as indicated is known as integrity monitoring. When integrity monitoring triggers a sensor malfunction alarm, a self-diagnostic function determines which sensor is defective.

In NILS, reliability will therefore be provided not by parallel systems but by integrity monitoring and self-diagnosis. Self-diagnosis is based on analytical redundancy, i.e. using knowledge of the relationships between the various navigation quantities to apply model-based fault detection and diagnosis in determining which sensor has started generating erroneous information.

The information from the integrity monitoring and self-diagnosis system is then used to degrade the landing system from its highest operating mode to a lower mode. The aim is to achieve the highest possible performance given the number of available sensors. Although the system is highly integrated, it must not collapse like a house of cards in a malfunction. Instead, there must be a graceful degradation.

Final certification of the landing system will present a challenge, since it is not equipment that is to be certificated, as is normally the case, but rather a collection of algorithms and their statistical properties. Consequently, a new methodology will be used. The methodology for certification will be taken from civil aviation and is named RNP (Required Navigation Performance). RNP is based on expressing the risk of undesirable events. For example, the risk of being outside the unobstructed area at an airport must be very low since the risk of a collision will then be high. The requirements can be visualized as two tunnels (an inner and an outer). If the uncertainty in position determination is seen as a 3-D bubble around the aircraft, the requirements will be met if the aircraft, including the bubble, succeeds in reaching decision height without the bubble touching the tunnel wall. This is shown in the accompanying illustration.

FUTURE POTENTIAL

The navigation system plays a more central role in an aircraft than one might expect. Apart from affording the Gripen pilot more flexibility in choice of airfield for landing than the pilot of any other aircraft in the world, it opens up a number of other possibilities in which the terrain database plays a critical role:

- Automatic pull-up if there is a risk of collision with the ground. This is also a very useful function for civil aircraft since a common causes of accidents is CFIT (Controlled Flight Into Terrain).
- Synthetic terrain display in the HUD (Head-Up Display) to assist low-altitude flying at night.

by Katarina Nilsson
Saab AB, Gripen

Design of systems that are optimal and insensitive to variation

Katarina Nilsson graduated in 1985 from the Swedish Royal Institute of Technology as a chemical engineer, having focused on chemical equipment engineering. She subsequently was involved in heat engineering at Studsvik AB for three years before working on energy technology at Linköping Institute of Technology, where she gained her Ph.D in 1993. Her main orientation was in the development of a cost-optimization tool for industrial process and energy systems. Since 1995, Katarina has been working in the Basic Aircraft Systems department of the Gripen business unit, where she is currently project manager for R&D activities.

In the system development process where several tools for modeling and simulation are commonly used, a comprehensive picture of system performance can be obtained. An optimal system design must also include some reference to robustness. It is of interest to know whether the optimal design renders a stable system performance or if deviations due to parameter variability will cause a non-optimal solution. Since the levels of some system parameters can be chosen at the design stage, they can be given values that will reduce or eliminate the effect of other disturbing parameters. A difficulty in finding a robust and optimal system design is how to include the natural variation of the real system in a model. Usually, system performance is investigated by changing parameters one by one. This is a tedious task and some information, such as interaction between parameters, is difficult to find. One method of meeting these demands is to combine optimization with experimental design. Optimization is then used to locate the optimal area and experimental design is used to introduce variation and disturbances that may occur in the system. This method describes a way to find a robust optimal design where the influence of variation of system parameters is considered.

Background

In order to support the system development process, a commercial integration environment is being introduced at Saab. This environment is designed as a platform for all system development work, where processes are modeled, roles are defined and tools are integrated. The purpose is to provide a corporate integrated systems engineering environment for all projects with a common user interface. This methodology will enable implementation and control of processes, where traceability and configuration control can be achieved. In order to achieve broad applicability, the choice of tools to be used in this environment is significant.

The 'general systems' of the Gripen aircraft embrace several different support functions, e.g. the environmental control, hydraulic and fuel systems. These systems include a variety of components with interactions and nonlinear relations. They are also subject to operation and safety requirements that must be guaranteed. The ability to analyze the complex reality that is addressed in these systems requires modeling tools for both software and hardware. Possibilities to integrate and combine tools to achieve increased applicability are of great interest.

The modeling approach today for Gripen general systems is to integrate a software model as a control unit in a hardware simulation model. This approach is also being tested for the addition of design tools, i.e. optimization methods. The method described here also includes experimental design that provides a strategy to find a robust and optimal design.

Introduction

The variation that will occur in a real system may lead to changes in the overall system performance. Examples of such changes are system parameters varying within allowed tolerances, variation occurring in the environment of the system and recur-

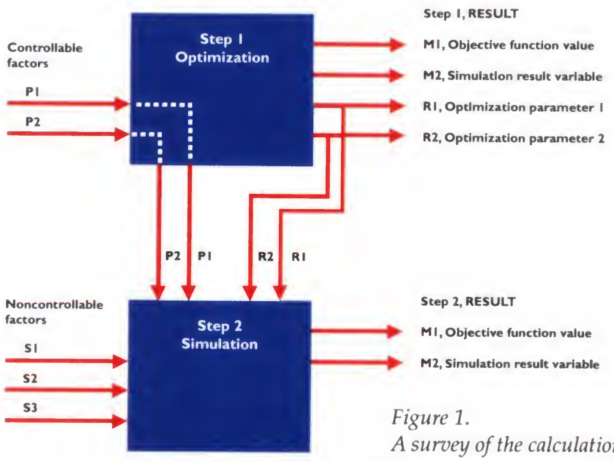


Figure 1.
A survey of the calculation procedure.

ring maintenance measures that involve parameter changes. Some of these variations affect system performance to a larger extent than others and interaction between parameters may also have some influence. When many components interact and system performance is dependent on both hardware and software design, it is necessary to take parameter variation into account when design calculations are performed.

Among the set of parameters, both controllable and non-controllable factors can be distinguished. Controllable factors are those that can be given a value around which variation may occur, while the value of non-controllable factors and their variation can not be directly affected. The suggestion in this method is to find an optimal design where controllable factors can be given a value that will reduce or eliminate the influence of non-controllable factors, thus enhancing system performance stability. The result then becomes a trade-off between optimal system design and stability to parameter variation.

Description of the method

The purpose of this method [1] is to add a robustness analysis to the specific optimization and simulation methods that are used, i.e. the simulation tool Easy5 with an integrated model of the system control unit and a hybrid optimization method [2]. The hybrid optimization is a combination of a genetic algorithm and the Complex method. The optimization search is based only on the objective function value and the studied system is represented by a dynamic simulation model including both hardware and software. Optimization is performed as iterative jumps between optimization search and simulation of system performance.

The calculations are performed in two steps, where step one involves optimization with varying controllable system factors and step two involves simulation with varying non-controllable system factors (see Figure 1). Both steps can be performed as

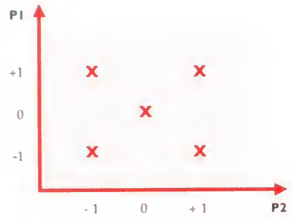


Figure 2. A two-level orthogonal array viewed as a square with a center point.

full-scale or reduced factorial experiments, where the parameter variation is induced by orthogonal arrays.

Variation can be introduced in the calculation by different experimental designs. A two-level orthogonal design with a center point is shown in Figure 2. The corresponding variation of the controllable and the non-controllable (without center point) factors is shown in Figure 3.

When probabilistic optimization methods like genetic algorithms are used, optimality can not be mathematically proven. This implies that a calculated result must be verified by a number of test calculations. The method suggested here will, besides the introduction of variation, also provide a structure for such verification.

The result of the statistical evaluation is obtained as polynomials, showing how the response variables are affected by variation of the controllable and the non-controllable factors.

In an alternative result analysis, where interaction effects between controllable and non-controllable factors are evaluated, further information about the system can be obtained. It is then possible to show how controllable system parameter values can be chosen to reduce or eliminate the influence of non-controllable parameters. In this way, system performance (optimality) is traded for system robustness with respect to parameters that are hard to control. The overall result will be a system design where the variation of controllable and non-controllable factors is considered.

Case study

The method has been applied to a dynamic simulation model of a small hydraulic system. The modeled system includes a pump, an accumulator, a pipe volume and a flow valve. The task was to find the optimal size of the system pump and a way to reduce fluctuations in system performance due to known system parameter variation. The parameters studied were:

- Varying controllable parameters
  - Accumulator discharge diameter
  - Accumulator precharge pressure

- Varying non-controllable parameters
  - Pump outlet power
  - Variation in accumulator precharge pressure
  - Entrainment of air

Controllable factors		
No.	P1	P2
1	-1	-1
2	+1	-1
3	-1	+1
4	+1	+1
5	0	0

Noncontrollable factors			
No.	S1	S2	S3
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1

Figure 3. A two-level orthogonal array for two factors with a center point (controllable) and for three factors without center point (non-controllable).

The calculated solution to this task was to increase the precharge pressure of the accumulator. This implies that a smaller size of pump can be chosen and a more stable system performance can be achieved. The influence of variation in output power from the pump will be reduced.

References

1. K. Nilsson, O. Åkerlund and A. Hynén, Using optimization and statistical methods to analyze the robustness of integrated hardware/software systems, The Fifth Scandinavian Conference on Fluid Power, Linköping, May 28-30, 1997.

2. K. Nilsson, Hybrid optimization method as a strategy to increase reliability in the design of complex systems, 1996 Avionics Conference and Exhibition, London, November 20-21, 1996.

by Peter Ljungberg and Ralf G. Kihlén Saab Dynamics AB

Multispectral imaging MWIR sensor for determination of spectral target signatures

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Ralf Kihlén is System Manager for infrared system at Saab Dynamics in Gothenburg. He has a Ph.D in electrical engineering from Chalmers University of Technology. Since 1973 he has been involved in IR systems design and development at Saab Dynamics, accumulating 24 years of experience in IR measurements, atmospheric propagation modelling, sensor design, signal processing, performance calculations and field testing. Ralf Kihlén can be contacted by e-mail: ralf.kihlen@dynamics.saab.se or by phone 031-3370244.

INTRODUCTION

In today's development of advanced modern defense systems two competing trends can be clearly discerned:

- Signature reduction of targets (stealth)
- Improved sensors

In the design of virtually all major modern defense systems, such as missiles, aircraft, vehicles, etc., the reduction and adaptation of target signatures to the background in which they are to operate is a major concern. In addition, countermeasures are more and more being adapted to replicate the targets that they are to protect. These developments are making the task for sensors more and more challenging, and are driving a quest for novel ways to improve the target recognition and countermeasure rejection capability of such sensors. Much effort is put into the development of infrared (i.e. thermal-imaging) sensors for defeating targets with stealth characteristics.

Thermal-imaging sensors extend our vision beyond the short-wavelength red (<0.7 µm) into the infrared (2-14 µm) by making visible the light naturally emitted by warm objects. Using thermal-imaging systems, the necessity of illuminating an object is avoided. This makes infrared (IR) sensors an extremely powerful tool for observation, acquisition and tracking both during the day and at night. IR sensors have been utilized by the military since the 1940s and are today an essential tool in most types of defense systems. In addition, the use of IR sensors in the civilian market has greatly expanded during the past few years thanks to the appearance of relatively cheap, uncooled systems. Today, IR sensors are being put to use in such disparate areas as fire-fighting, search-and-rescue, medical research, quality control and chemical/electrical plant inspections.

The earliest types of electronic IR sensor utilized single-element detectors. In order to build up an image, the scene had to be optically scanned across the detector in two dimensions, usually by the use of moving mirrors and prisms. Second-generation IR sensors extended the number of detectors to linear arrays, which enabled one of the scanning dimensions to be eliminated. Still, the necessity for optical scanning in these sensors significantly limited the time devoted to collecting radiation from each point in the image space, thus reducing sensitivity and/or frame rate. During the past few years, high-sensitivity two-dimensional focal-plane arrays (FPAs) with a very large number of pixels have been developed, and are now available on the market in significant numbers and at reasonable prices. The use of such FPAs has increased the possibility for each separate detector element to collect data. This can be used either to increase the integration time or to increase the frame rate of the collected image.

Today's large FPAs can have a very high frame rate (>500 Hz). This can, for example, be utilized to achieve a good temporal resolution of the collected data from one wavelength band. An alternative is to use this frame rate combined with a wavelength-selective element to collect data

from several wavelength bands, thereby collecting not only amplitude information about the scene studied, but also information regarding the spectral distribution of the collected signal. This data, in turn, can increase the capability of the IR sensor to distinguish between target, countermeasure and background. Such a capability will improve the chance of detecting and identifying targets with a reduced signature (stealth targets).

In order to gather experience in this area, and to collect data necessary for the construction of efficient IR seekers, we have developed a multispectral IR sensor. This sensor operates in the 2-5 µm waveband and can be used either to collect general data or to directly simulate a seeker prototype.

SENSOR DESCRIPTION

The three main parts of the sensor consist of optics for image formation and wavelength selection, an FPA detector with its associated electronics for collecting and storing an image, and software for recording the images (see Figure 1). The optics, detector, analog/digital (A/D) electronics and cooling are contained in a separate sensor head, while the detector timing circuits, image processing and storage electronics are contained in a standard PC-type industrial computer connected to the sensor head by a single cable.

Optics

The imaging optics consist of a 100 mm f/1.5 lens with an overall field-of-view of 3.7° x 3.7° and an instantaneous field-of-view of 0.5 mrad. This lens provides excellent imagery within the 3-5 µm band. The wavelength-selection part of the optics consists of a rotating filter wheel containing six filters. In the present sensor, these filters cover the 2-5 µm waveband in 0.5 µm-wide bands. The filter wheel can easily be exchanged, which allows the position and width of the utilized wavebands to be adapted to specific applications at a modest cost. The detector wheel is driven by a constant-speed electric motor and is synchronized to the image collection by two reading forks which detect the appearance of each filter in front of the detector as well as the completion of one complete circuit of the filter wheel.

Detector and electronics

The 128 x 128 MCT (mercury-cadmium-telluride) detector is sensitive in the 2-5 µm part of the IR spectrum. This detector has an effective frame rate of 200 Hz. The use of six different wavelength channels consequently gives us 33 multispectral images every second. At this frame rate, the maximum possible integration time is about 2.2 ms, limited by the residence time of each filter in front of the detector. Nevertheless, this time is long enough to enable the collection of useful data even from low-signature background-adapted targets.

The electronics integrated into the sensor head include integration time control and A/D conversion. The integration time for the various spectral channels can be individually controlled. This enables the user to utilize the optimum integration times applicable to the target for each specific wavelength band. The A/D converter gives a 14-bit digital output which is fed to a buffer memory, used to store a sequence of images during acquisition. After acquisition, the images can be downloaded to a hard disk for permanent storage. The 128 MB currently used enables us to store a 20-second sequence at the full frame rate of 33 multispectral images per second. The images are corrected for detector non-uniformity and drift by the use of a 2-point correction routine. This 2-point correction is related to images collected using uniform high- and low-temperature references, and is necessary for good image quality.

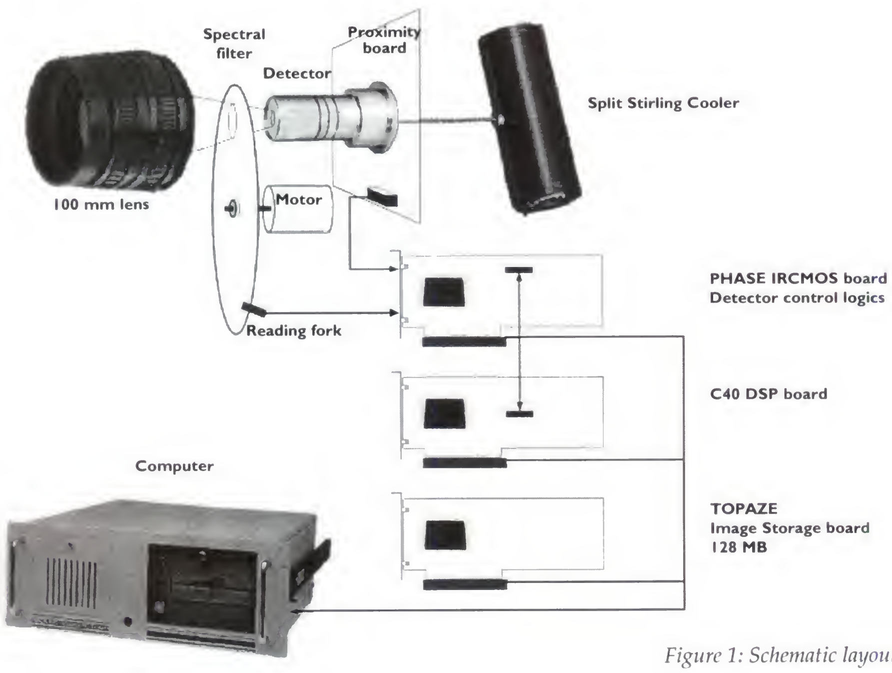


Figure 1: Schematic layout of sensor.

Software

The data acquisition software is a development of the SAPHIR software produced by CEDIP SA (France). The software has been adapted to the collection of multispectral data. The main purpose of this program is to collect, store and display the measured data. Some of the most important functions integrated into the software include: control of integration times, data acquisition control, bad pixel removal, 2-point normalization, data export (ASCII, TIFF, etc.), simple image processing (averaging, filtering, addition and subtraction of images) and simple analysis (profiles, histograms, spatial integration, etc.). For the measurements performed by us, the program was primarily used for data acquisition, and the data then exported to more sophisticated image-processing programs for the detailed processing and analysis.

MULTISPECTRAL MEASUREMENTS

The multispectral sensor developed by us has been used to initiate a comprehensive measurement program to map the spectral characteristics of targets, backgrounds and countermeasures in the MWIR region. Typical targets can include aircraft, ships, vehicles and structures; typical backgrounds are blue sky, cloudy skies, and ground or sea clutter; countermeasures can include old and new flares, directed countermeasures, etc. The data can then be used for example to optimize the spectral characteristics of a sensor.

In the case of an aircraft as a target, the IR signature emanates from a number of radiating surfaces with very different characteristics. The parts of an aircraft traditionally used by an IR seeker are the engine nozzle and the exhaust plume. However, today's imaging seekers are increasingly also exploiting the radiation from the rest of the aircraft structure (fuselage). The spectral signature of an aircraft can thus become quite complex if the target is spatially unresolved, since it is a superposition of several components with different spectral behavior. In order to optimize the performance of a seeker, it is thus of importance to collect detailed data regarding the spectral signature of the complete target, as well as the relevant backgrounds, such as blue sky, haze and clouds, and countermeasures.

The purpose of the measurements performed so far has primarily been to verify the characteristics of the system and to develop procedures for multispectral measurements. We have collected data in a variety of environments, mainly concentrating on maritime data (in the entrance to Göteborg harbor) and aerial data (commercial airliners and Swedish Air Force transport and combat aircraft in both blue-sky and cloud backgrounds). These activities have given us a substantial database of images, the analysis of which is currently under way.

RESULTS AND DISCUSSION

Some results from the initial measurements made by the multispectral sensor are presented in Figures 2-4. The results are presented as color pictures, which have been produced by combining three waveband channels with each channel representing a different color (2.0-2.5 µm is blue, 3.5-4.0 µm is green and 4.5-5.0 µm is red). The intensity of each separate channel has been adjusted for maximum contrast. Consequently, no comparison of absolute irradiance values should be made between the different spectral bands in these images. However, a comparison of the distribution of the irradiance between different features in each image can still give some interesting insights.

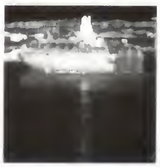


Figure 2: 2-5 µm grayscale image of a North Sea ferry in sunny weather at a distance of 2 km.

Figure 2 shows a North Sea ferry at a distance of 2 km. The weather is sunny with good visibility. This grayscale image shows the accumulated signals from the 2.0-2.5, 3.5-4.0 and 4.5-5.0 µm wavebands. This is thus an example of what a conventional, single-waveband sensor would see. A few bright details can be seen, for example the funnel of the ferry, the hull and some oil containers on shore. However, it is difficult to distinguish between different objects with a similar brightness.

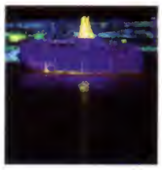


Figure 3: Spectrally segmented image of a North Sea ferry in sunny weather at a distance of 2 km. The colors represent: blue: 2.0-2.5 µm; green: 3.5-4.0 µm; red: 4.5-5.0 µm.

Figure 3 shows the same scene as Figure 2 but using the coloring technique described above. This immediately shows the more detailed information that can be made available to the observer by combining data from several different spectral channels. An obvious observation is that the brighter parts of the image have now been divided into basically two classes: blue features (for example the ferry hull) and yellow (the funnel). The blue features represent a signal dominance in the 2.0-2.5 µm waveband rather than the longer wavelengths. This difference results from the prevalence of reflected solar radiation in this band, making high-reflectivity surfaces appear very bright. For example, the ferry is painted in a white color which has good reflectivity. For the longer wavelength bands, however, thermal radiation emitted by heated objects becomes more and more apparent. This can be clearly seen by observing the yellow color of the hot ferry funnel, which indicates a dominance of green (i.e. 3.5-4.0 µm) and blue (4.5-5.0 µm). Also, the traces of a warm substance (water or air) running down the sides of the ship can be clearly discerned as yellow streaks on a blue background. This was not visible in the original grayscale image.

Figure 4 shows a four-engine turboprop transport aircraft at a distance of 1.5 km. The four bright yellow spots show the thermal emission above 3.5 µm from the engines. The background clutter from the clouds is

mainly blue-green, which indicates that the longer wavebands would be a first choice for tracking aircraft since the target signal is maximized and the background clutter minimized. However, a more detailed analysis is necessary in order to account for varying background clutter scenarios, varying weather, countermeasures and other important parameters. We are currently using this multispectral sensor to collect data that will make such an analysis possible.

Figure 4 Spectrally segmented image of a four-engine turboprop transport aircraft. The colors represent: blue: 2.0-2.5 μm; green: 3.5-4.0 μm; red: 4.5-5.0 μm.

SUMMARY AND CONCLUSIONS

The principles of a multispectral imaging MWIR sensor have been presented. This device utilizes the high frame rate made possible by modern FPA arrays. Such an array has been combined with a rapidly rotating filter wheel, thereby producing images of 128x128 pixels in six wavelength bands in the 2-5 μm region at a frame rate exceeding 30 Hz in each band. The sensor has the capability to perform two-point correction in real time, thereby compensating for the different dynamic ranges in each spectral band. An extensive measurement program is in progress for gathering data for targets, countermeasures and backgrounds. Selected results from this program are presented. These results show the great variation in signature in different wavelength bands from various targets and backgrounds. These differences result both from variations in the transmission of the atmosphere and from differences in surface reflectivity, emissivities and temperature. Further work is in progress on collecting more data from different types of targets and environments, as well as dealing with analysis of the data and the inclusion of image-processing algorithms that can take full advantage of multispectral image data.

by Cecilia Laurén
Combitech Network AB

IT Security – a way of life

Cecilia Laurén has an educational background in applied systems science, with a Master's in information security from Stockholm University. She has many years' practical experience of IT security, having worked with military as well as civil systems. She is currently employed by Combitech Network AB, Stockholm, and works partly with customer projects and partly with building up IT security operations.

There is nothing new about security. As early as 1916, Henri Fayol* saw that having and maintaining a "secure" position was one of the most important management functions or, as he put it: "all measures conferring security upon the undertaking and the requisite peace of mind upon the personnel." Fayol's emphasis on the role of management is equally significant today and is an essential factor in achieving security. The more specific area of information technology (IT) security is not new either. IT security was identified as a problem many years ago. Despite it being more than 25 years since the modern computer was first developed, it is not just that some systems are vulnerable to incorrect use, they are also used by people who are unaware of their weaknesses or even disregard them.

IT security work will try to create and secure companies' or organizations' superiority as regards the ability to manage and conduct their operations. It will also contribute to securing cost-efficient and technologically balanced protection for IT information.

The threat to our systems becomes more complex when related activities of a more conventional kind are supplemented or replaced with advanced technology. The consequences of such activities become more all-encompassing as they become more reliant on technical functions. The possibility of discovering information loss or a deliberate manipulation is small, which is why the need for preventative protective measures increases as IT technology develops. From a security perspective, the utilization of IT often involves a certain amount of risk, which can be summarized as follows:

- Unauthorized access to information, and/or
- Limited/no access to information in the prescribed time and the required form, and/or
- Unauthorized changes, deletions or the falsification of information.

IT security projects must be based on a set of methods, techniques and tools.

Problems

The first problem is that no computer software program is fault-free. The existence of a fault can be shown or proved, but demonstrating that a program is fault-free is impossible with today's methods. As security functions in computer systems are implemented in the software, it cannot be proved that they will work free of fault. In other words, there is a certain risk that the security functions can be bypassed.

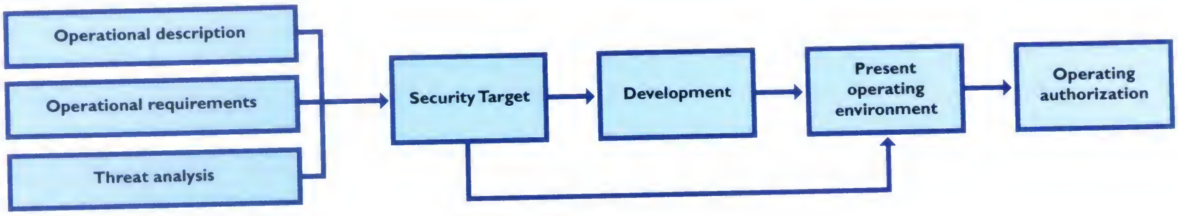
Another problem is determining which security functions should be used in any given system. This is influenced primarily by the sensitivity of the information which is stored or extracted from the system, and secondly by the degree of exposure that the information can be given.

A third problem is that the threat to computer systems changes with time, because:

- Use of the system means that, in time, any remaining security flaws will be revealed.
- The way in which systems are used changes, which generally means that sensitive information is more exposed.
- Computer systems are increasingly being integrated with other technical systems (e.g. aircraft, ships, control centers), which in turn are also subject to integration, resulting in further exposure.

* French industrialist, around 1900.

** The document that specifies threats, requirements and security functionality for any given system.



Overview, System Operating Authorization

Development

During the 1980s, the need for security in computer systems was given increasingly wide attention. This need was especially noticeable in various countries' military establishments and resulted in a number of requirements for security in computer systems, starting with the US Defense Department TCSEC 1983 (revised 1985) and followed by the European ITSEC (1991). Because research and development in IT security has mainly been conducted on the initiative of the military, these requirements have leaned heavily towards confidentiality. Theoretical work concerning integrity and information accessibility has not progressed to the same degree.

Technical security in IT systems has two aspects – correctness and effectiveness. The latter is the subject of major international collaborative efforts such as the development of criteria and methods for evaluation. An important motive behind this collaboration is the reduction of costs for development and evaluation of standard products, particularly in the civilian market. This is especially noticeable in that development is led by organizations and authorities primarily connected with trade and commerce – the European Commission in particular.

The prevailing attitude within international IT security circles regarding how to develop and maintain a "secure" IT system is based on a number of simple principles, the most important of which are:

- The systems or products to be integrated must be built and documented for integration.
- The purposes of the security functions must be clear.
- The security functions' specifications must (as far as possible) also be explicit.
- The security functions' construction must include traceability from the requirements to implementation.
- Evaluation of the security functions' specifications, construction and implementation must be made repeatable, reproducible, objective and impartial.

Requirements

Demands for security in IT-based systems are usually based on a combination of perceived threats and requirements born of laws and regulations. On the other hand, the tendency is for information systems to be developed through the successive integration of components, subsystems and systems into huge systems that also comprise many other types of systems, including production management systems. Basing the development of components, subsystems or systems only on the threats and laws which appear to be relevant for that particular object will probably result in a system with security protection that is not consistent and has no real purpose. It is necessary also to take into consideration the system's business-related requirements and to ensure that the security architecture defines a distribution of the protection functions throughout all parts of the system.

Given a more specific picture of the requirements, the ability to plan and calculate the cost of systems development can be improved significantly. Clearer requirements for the authorization to put a system into operation (from an IT security perspective) and the existence of a security architecture would lead to improved monitoring of costs in these development projects.

Evaluating security

The process that has as its purpose to monitor whether a product/system satisfies certain requirements for correctness and effectiveness is called certification. Certification procedures result in the issue of a certificate showing that the product/system concerned has been found to satisfy

the relevant requirements. The issue of the certificate is preceded by a technical evaluation.

Such a technical evaluation includes an analysis or test of the product/system. This part of the evaluation attempts methodically to identify as many flaws in the security system as possible. This results in documentation that helps in assessing the product's or system's resistance to potential attack, and how solid the basis is for assuming that its defense system cannot be by-passed. Carrying out a technical evaluation requires, among other things, knowledge of attack and defense techniques. The bulk of information increases as the evaluation proceeds and this can then be channeled back to the customer (who drew up the requirements) as supporting documentation for improved requirements for future security.

Methods of evaluation

As guidelines for assessing the amount of time and resources used in the technical evaluation, the stages of such an evaluation should be briefly described. The technical evaluation is carried out at three integration levels:

System, where the evaluation attempts to monitor that the Security Target** of business-related requirements has been converted into information-technical terms, and that these requirements are complete and free from internal contradiction. This level must include the principles which form the basis for the acquisition of information. These principles must also be evaluated with regard to their suitability to meet a given threat. An overall system architecture should also appear which, as regards security, describes how specified security functions should be localized to various subsystems or components. Should such an architecture exist, it should be evaluated with regard to the security functions' ability to combine into a defensive whole.
Subsystem, which encompasses the same evaluation activities as on the systems integration level but for each subsystem, which makes this a more detailed level.
Components, for which the evaluation consists of monitoring that the requirements for their security functions which are formulated at the system or subsystem level are satisfied.

This evaluation and analysis results in a list of conceivable or defined security flaws. The evaluation should conclude with a penetration test based on this list, as well as an analysis of the level at which the flaw can be exploited by the attacker defined in the Security Target.

Documentation for operating authorization

The purpose of producing documentation for operating authorization (from an IT security perspective) is to provide knowledge of the IT system's ability to protect information.

Authorization should take into consideration the collected security system's ability to protect the information system's values against threat. In addition to the technical evaluation of what is implemented in the IT system, security measures are divided into the following categories:
Administrative and organizational measures. Regulations, routines, staff security checks and training are the main examples of administrative measures. Organizational measures consist mainly of delegating responsibility and authorization.
Other technical measures. These measures consist mainly of facility-technical measures, e.g. security monitoring systems and cable extensions.

Summary

It is important for the security system's suitability that the protective measures are specified and constructed so that they:
Deal with given threats, mainly through preventing a potential attack but also in other ways, such as making an attack too difficult and therefore too costly for it to be viable.
Combine to form a whole, mainly through ensuring that the individual parts support each other in such a way that any by-pass is cut off.
Resist attack, and
Cannot be "pacified" without this being detected.

Risk is an integral part of life. We take a risk whenever we cross the street, fly to the Canary Islands or play football. Ever since we were children, however, we have learned to live with these risks and consciously weigh the pros and the cons. To increase the knowledge of how company-sensitive information is to be handled is to make it easier to produce well founded decisions. This may either mean increased investment in security functions or the conscious taking of risks.

Combitech Network AB ensures that its customers have access to information via a computer network when required. The company provides a comprehensive range of services based on IT security for organizations that prioritize user support, technology, flexibility and security. Combitech Network AB's customers are major companies and organizations in Sweden who place high demands on confidentiality, accessibility and computer secrecy.

Experimental results from fusion of binary correlation filters implemented in an optical correlator

by Jan R. Johansson and
David G. Rabelius
Saab Dynamics AB

Over the years many correlation filter designs for automatic target recognition have been proposed. Some designs have high tolerance to different types of noise and clutter but with the disadvantage of correlation peaks that are not very sharp. Other designs give sharp correlation peaks but have low tolerance to disturbances. A fusion of different types of filter, where the weaknesses of each design can be avoided and the strengths preserved, has earlier been proposed. We have used an optical correlator with binary Spatial Light Modulators (SLMs). Because of this, the complex grayscale correlation filters are binarized. The input image is edge-enhanced and binarized before entering the system. By using different binarizations, the filters produce different false-alarm peaks but equivalent correlation peaks in the correlation plane. Optical correlation is performed with the filters and the results are fused, giving the resulting correlation image. Fusion of the results leads to suppression of false alarms and enhancement of the true correlation peaks. Tests have been performed on both high- and low-contrast cluttered images with good results.

INTRODUCTION

Recently much interest has been focused on the concept of real-time image and pattern processing, and especially on the problem of constructing a system capable of high-speed pattern recognition. In short, the pattern recognition problem consists of finding the one signal in a set of memorized ones which best matches a given input signal. There are many applications where pattern recognition is useful: military, space and medicine are some. Pattern recognition can be done in several ways, for example by feature extraction, blob analysis and correlation. Correlation is a method that is robust and easy to implement, but it uses Fourier transforms which, when implemented in a digital system, are very time-consuming and lead to a large system that consumes a lot of power. In some applications, particularly military, there are severe limitations on weight, power consumption and size. Correlation can also be implemented in optics by the use of Fourier optics. This gives an optical correlator that is both fast and small, and which uses less power than a digital system.

Since VanderLugt published his, for this area, pioneering article in 1964, much research effort has been put into constructing different types of optical correlator and filter to gain good performance. At first, different types of holographic technique or photographic film were used to enter the input images and correlation filters into the system. Today this is done with Spatial Light Modulators (SLMs).

Since the filter that is to be introduced to the system is complex-valued and has continuous amplitude levels, it must undergo some type of coding for it to be sent to an SLM. In our project, we have worked with a correlator with binary SLMs and accordingly some kind of binarization is needed, i.e., the pixels must be set to one or zero with respect to a given criterion.

Many types of correlation filter optimized for different criteria have been proposed. VanderLugt used the matched filter, which is optimal in respect to additive noise. Other design parameters used to optimize filters are variance of the correlation peak, peak energy compared to total energy of the correlation plane, and the peak-to-sidelobe ratio. All these methods yield filters with different characteristics. This means that the filters respond differently to disturbances such as noise and distortions in an input image. They also have varying discrimination capabilities between similar targets. In target detection and identification applications, OTSDF filters (Optimum Trade-off Synthetic Discriminant Filters) are often used to gain invariance to predictable distortions such as rotation and scaling.

An image-processing system with an optical processor can contain some type of digital processing of the input images and the correlation results. An evaluation of the correlation plane is performed in the post-processing of the correlation result. In addition to the true correlation peaks, false peaks appear from the cross-correlation of the correlation filter with the background noise and objects other than the true target. With a high level of noise in the input images, these false

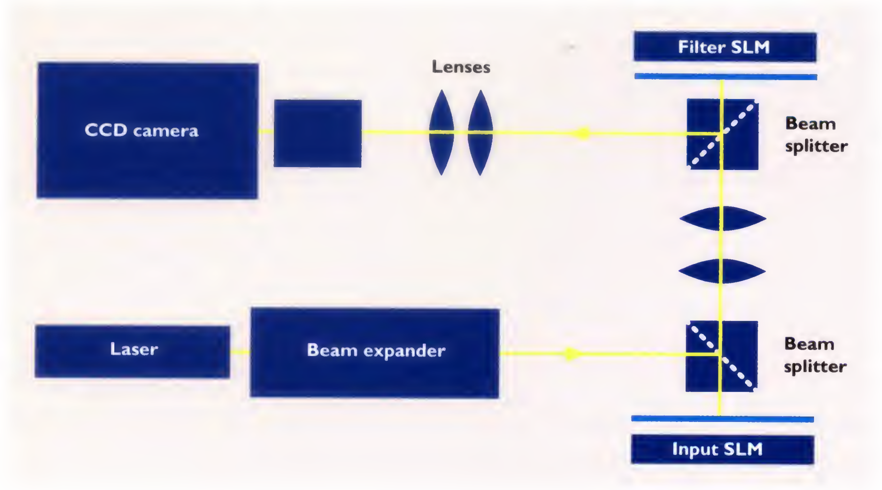


Figure 1. Schematic description of an optical correlator

peaks repeatedly cause false targets to be reported. Filters constructed with different approaches as regards which criteria are optimized give different background peaks in the correlation plane. By combining the correlation results from two or more filters, false peaks can be suppressed while the true peaks are left unaffected, giving improved performance.

OPTICAL CORRELATION

Figure 1 gives a very schematic representation of an optical correlator. A laser diode collimated beam is expanded and sent to the first SLM, which displays an image to be processed. After reflection on the SLM, the light beam passes through the first beam splitter. The image is then Fourier-transformed by a pair of lenses and imaged on to the filter SLM after having passed through a second beam splitter. In the Fourier plane, the Fourier transform of the input image is therefore multiplied by the filter displayed in the filter SLM. The resulting beam is reflected on the second beam splitter and Fourier-transformed by a second pair of lenses. The processed image is finally captured by a fast digital camera.

The correlator we have used in the project has been built by the Swedish Institute of Optical Research (IOF) within the Swedish national program for optical information processing. The correlator has been built with commercially available products only and is a rugged lab system with good tolerance to vibrations. The footprint of the system is A4 (21 x 28 cm).

METHODS

We have developed a method based on both digital and optical image processing, i.e. a hybrid system. The optical correlator can be seen as a very fast 2-D Fourier transform processor. The hybrid system is divided into three parts, pre-processing, optical correlation and post-processing. Two binary filters with different responses to false correlation peaks are made from a complex-valued OTSDF filter. An overview of the structure is shown in Figure 2.

Pre-processing: Targets are often made of sharp edges and the background is of a low-pass nature. This makes it natural to perform some kind of edge enhancement to improve the images. In this case a derivative Sobel filter followed by a threshold, with value β_1, is used. This produces a binary version of the input image. Pre-processing is carried out in a digital processor, in our case a frame grabber from Imaging Technology Inc.

Optical correlation: In the correlation we use two binary filters applied in series. The results are stored in a computer for post-processing. The filters have been made from a complex-valued OTSDF filter, H. The OTSDF filter is constructed using a number of reference images with different rotation and scaling. Because of the binary SLMs, the filter must be binarized. It is natural to use the phase information when binarizing since most of the information in an image can be found in the phase.

Post-processing: Post-processing in our method is a fusion of the correlation result achieved from the two binary filters. The fusion is simply a multiplication of the correlation results followed by a threshold, with value β_2.

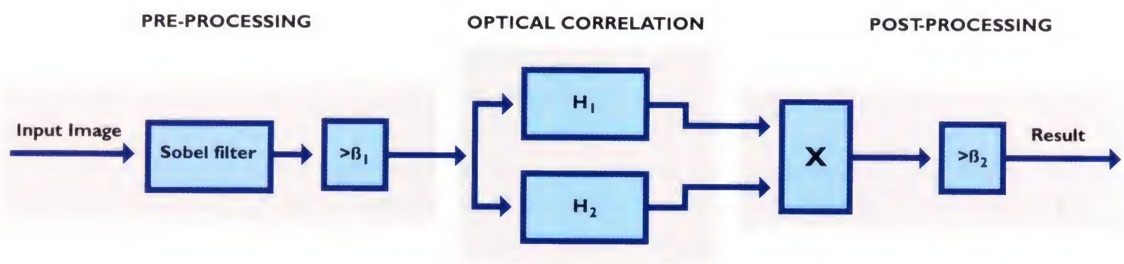


Figure 2. Structure of hybrid system

Binarization: Our method uses two binary filters, H_1 and H_2, which can be written as:

$$H_1 = \begin{cases} 1, \text{ if } \mathrm{Re}\,\{He^{-j\phi_1}\} > 0 \\ 0, \text{ otherwise} \end{cases} \quad (1)$$

$$H_2 = \begin{cases} 1, \text{ if } \mathrm{Re}\,\{He^{-j\phi_2}\} > 0 \\ 0, \text{ otherwise} \end{cases} \quad (2)$$

where ϕ_1 and ϕ_2 are the angles which fulfill the following two conditions:

1. The angles give the best and second-best discrimination to false targets.
2. $\Delta\phi = |\phi_1 - \phi_2| > \alpha$, this condition being necessary for the two binary filters to have different correlation responses to the background. If $\Delta\phi$ is small ($<\alpha$) the filter will not produce a sufficiently different correlation result. In our experiments, we have used $\alpha = \pi/3$.

This construction method produces two filters with the same response to true targets and different cross-correlation responses to the background and/or false targets.

Figure 3. Test image (left), binary version (right)

EXPERIMENTAL RESULTS

When evaluating the performance of our method, we have used a number of test images with different characteristics. These contain targets (false and true) which have different positions, size, rotation, background and so on. In order to fit the binary SLMs, the images must be binarized as previously described. Figure 3 shows an example of a test image and its binary version.

The filters used for the experiment and simulation were made from a complex-valued OTSDF filter. Only one OTSDF filter/group has been used. The filters were made from characteristic reference images covering the variation in scaling and in- and out-of-plane rotation present in the different groups. The filters were binarized as previously described.

Figure 4 shows an example of the result after correlation. The peak in the correlation plane gives the location of the detected object. We have tested our method on 86 images. The detection probability was about 75% and the false-alarm probability about 10%.

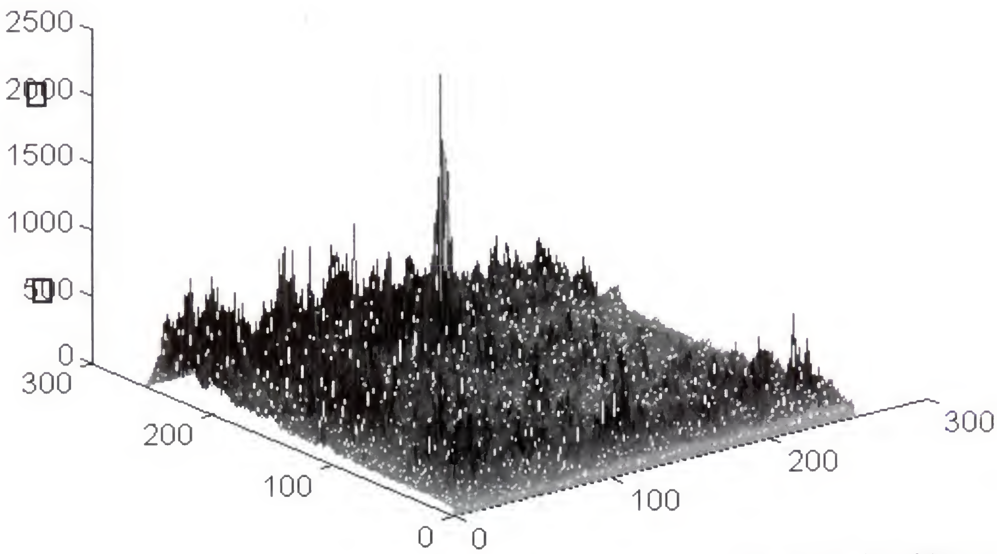


Figure 4. Product of the two correlation planes from the binary filters

by Karin Berggren
Saab Training Systems AB

The Saab Training Systems after-sales concept in the US

Karin Berggren has been working at the CLS facility in Knoxville,TN, USA, since summer 1997. Before that she worked at the After Sales department in Sweden, involved in supporting and further developing Saab Training Systems after sales concepts. Karin has a Master of Science in Industrial Engineering and Management, specializing in logistics.

The Saab BT 46 laser simulation device offers realistic training in precision gunnery and force-on-force combat for armored vehicles. The BT 46 accurately simulates the ballistics of live ammunition and presents the firing results to the crew on an LCD display. Target vehicles indicate hit and miss results with flashing strobes. The crews also receive audio messages generated by the simulator. For the US, the BT 46 has been adapted to meet the demanding requirements of the Tank Weapon Gunnery Simulation System/Precision Gunnery Simulator (TWGSS/PGS) program. The US Army and US Marine Corps use the system on the M1 Abrams tank, the Bradley Fighting Vehicle and the Light Armored Vehicle. The BT 46 is superior to the simulator previously used for similar training and comments from the users have been very positive.

Since deliveries began in 1995, more than 1,200 systems have been delivered to the US market. These are in use at 20 Army and Marine Corps facilities within the US and by US forces training at bases in Germany, Korea, Japan, and Kuwait. To provide support for the systems, Saab Training Systems has a Contractor Logistics Support (CLS) contract with the US Government. The support facility is located in Knoxville, Tennessee, which is centrally located in the eastern US and within driving distance of six of the military bases where equipment is used. The bases in Germany are supported from the company's after-sales department in Huskvarna, Sweden, while all other bases are supported from the CLS facility in Knoxville. The CLS works primarily with the Training Support Centers (TSCs) located at each military facility but most requests for information come directly from the troops.

The objective of the CLS concept in the US is to minimize system down-time for the user. The users and support personnel at the bases are able to get technical information and replacement parts quickly. This concept has contributed to the TWGSS/PGS program success in the US. To support this concept the CLS facility in Knoxville has test equipment, a stock of replacement units, spare parts and personnel. Parts of the investment have been paid for by the CLS contract with the US Government. Currently there are four persons working with the CLS activities, two Swedes and two Americans. We make up a good team, each member having expertise in different fields.

The military environment is tough. The BT 46 simulator consists of a number of modular units that incorporate advanced microcomputers, software and optical elements connected by a series of cables. These components are mounted inside as well as on the outside of the military vehicles. The systems are mounted and dismounted on the vehicles numerous times every month. The BT 46 system is designed to meet these high demands. Proper training is important to minimize damage due to faulty installation. Saab Training Systems has developed a "train-the-trainer" program where company personnel train military personnel to train users. These programs have been very successful and are highly appreciated by the users, reducing down-time significantly.

If something breaks or there is a technical problem, there is a toll-free telephone number to the CLS facility. The CLS personnel give on-line support by phone or e-mail on how to troubleshoot the system. The BT 46 system has a Built-In Test (BIT) function that helps the user locate the problem. If a

part is inoperative or damaged, we will ship a replacement via UPS on the same day it is requested and the parts will arrive at the base the next day. This is the key to achieving our goal – to reduce down-time for the user.

All necessary paperwork and labels for returning inoperative parts are included in the box with the replacement parts. All that is required is to put the bad parts in the box and give the CLS facility a call to inform us that there is a box ready to be returned. Within the continental US, the turn-around from the time a base calls until it has a replacement part is normally less than 24 hours. For replacements that are required outside the US, the CLS personnel arrange shipping with a freight forwarder as soon as a call is received. The freight forwarder also handles return shipments.

When a package has been returned to Knoxville, all parts are checked for damage and tested for faults. All obvious damage that is determined to be from abuse, misuse or neglect is considered to be non-warranty. All electronic units have a shock sensor that will trip if the unit is exposed to an excessive force (for example dropped). If the electronics in the unit do not work properly and the shock sensor is tripped, the repair is considered non-warranty. All damage that is considered non-warranty is photographed with a digital camera and the picture is saved along with the repair report. This information is included with the invoice to the US Government.

Most repairs are made on cables, brackets and electronic units including replacement of PCBs. The exception is the transceiver unit, which is the heart of the simulator. The need for a substantial investment in test equipment makes it not cost-effective to repair this unit outside the factory in Huskvarna, Sweden.

One important function of the CLS is to work closely with the support staff at the military bases. Therefore all major bases receive a visit from one of the CLS engineers at least once a year. This gives us the opportunity to see first-hand what kinds of problem, if any, the users are seeing and to help determine where improvements may be made. We also use these site visits to continue training and answer any questions they may have.

All feedback the CLS personnel get from users and troubleshooters, and information obtained from making repairs in Knoxville, are reported to the factory in Sweden. This is important information for the teams that design, develop and produce the BT 46 system in Sweden. Periodically a representative of the various product teams in Sweden comes to the CLS facility to assist during peak periods when there is a large simultaneous turn-in of equipment at many military bases. These persons can update the CLS personnel about any new repair techniques or software and gather data about the use and repair requirements of the product that can aid their team when they return to Sweden. In return, the CLS personnel learn more about specific BT 46 components.

To summarize, the key success factors for the CLS concept are:

- Minimize down-time
- Short turn-around times
- On-line support
- Knowledgeable personnel
- Good relationship with users and support personnel
- Open for feedback.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